Hydrology and Water Quality of the Shallow Aquifer System, Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
Measurements Reported in Inch-Pound Units		
Length		
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	0.4047	hectare (ha)
Velocity		
inch per hour (in/h)	25.4	millimeter per hour (mm/h)
foot per day (ft/d)	0.3048	meter per day (m/d)
Hydraulic Conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)
Measurements Reported in International System Units		
Length		
micrometer (µm)	0.0000003937	inch (in.)
millimeter (mm)	0.0003937	inch (in.)

Water temperature is reported in degree Celsius (°C), which can be converted to degree Fahrenheit (°F) by the following equation: °F = 1.8 (°C) + 32

Vertical datum: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929–a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units: Chemical concentration is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as mass (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Specific conductance of water is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Hydrology and Water Quality of the Shallow Aquifer System, Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia

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SUMMARY

Yorktown Battlefield, a part of Colonial National Historical Park, was the site of the culminating battle of the American Revolutionary War. The National Park Service operates and maintains the battlefield primarily to protect the historical and cultural resources of the area but also to protect the streams and wetlands. These streams and wetlands provide (1) critical habitat for rare, threatened, and endangered species; (2) nurseries for numerous commercial and recreational sport fisheries species; and (3) opportunities for observation, education, and recreational fishing. Because ground-water discharge from the shallow aquifer system can contribute more than half of the flow in the streams and a large part of the water to the wetlands, this discharge can substantially affect the quantity and quality of water in the streams, wetlands, and associated habitats near the battlefield. Consequently, knowledge of the hydrology and water quality of the shallow aquifer system is critical to the protection of these natural resources. In 1999, the U.S. Geological Survey, in cooperation with the National Park Service, began a preliminary delineation of aquifers and confining units and a general characterization of the hydrology and water quality of the shallow aquifer system near Yorktown Battlefield. One of the purposes of the study was to determine the types and amounts of additional information needed to evaluate the effects of the shallow aquifer system on the quantity and quality of water in the streams, wetlands, and associated habitats.

Yorktown Battlefield is underlain by a system of interlayered aquifers and confining units. The deep part of the aquifer system (generally deeper than 150 ft) is poorly connected to the shallow part of the aquifer system, streams, or wetlands. The shallow aquifer system is well connected to the streams and wetlands and is the main source of ground-water discharge. The shallow aquifer system at increasing depth consists of the Columbia aquifer, the Cornwallis Cave confining unit, the Cornwallis Cave aquifer, the Yorktown confining unit, and the Yorktown-Eastover aquifer.

The physiography near Yorktown Battlefield substantially affects flow through the shallow aquifer system through associated effects on the geology, stream incisement, and locations of recharge and discharge areas. Because terrace deposits are present at different elevations and are incised by stream valleys, sediments that form the Columbia aquifer and Cornwallis Cave confining unit form discontinuous rather than laterally continuous geohydrologic units. The Columbia aquifer and the Cornwallis Cave confining unit are also limited in extent because sediments that commonly form these units are unsaturated beneath the uplands near the stream valleys. Stream incisement also reduces the thickness of the Cornwallis Cave aquifer beneath the valleys and partly controls ground-water flow. Valleys of streams draining to the York River Basin are shorter and more deeply incised, have steeper walls, and are separated from one another by narrower upland terraces than valleys of streams draining to the James River Basin.

The Cornwallis Cave aquifer is the primary source of discharge from the shallow aquifer system. This aquifer underlies the entire battlefield except at the northwest boundary along Ballard Creek and the York River. Stream incisement into the Cornwallis Cave aquifer creates a good hydraulic connection between the aquifer and the streams and wetlands throughout the battlefield. Because streams do not incise through the Yorktown confining unit into the Yorktown-Eastover aquifer near the battlefield, the Yorktown-Eastover aquifer is poorly connected to the streams and wetlands near the battlefield.

Because of the good hydraulic connection between the streams and the Cornwallis Cave aquifer, shallow ground water generally discharges to local streams rather than flow under the streams to regional discharge areas. Therefore, the potential is limited for the transport of contaminants from recharge areas outside the battlefield through the shallow aquifer

system to the battlefield. Flow under streams to regional discharge areas most likely occurs through the Yorktown-Eastover aquifer, which is also the most likely pathway for the transport of contaminants from sources outside the battlefield to the battlefield. Contaminant transport through the Yorktown-Eastover aquifer, however, probably is limited by the low permeability of the overlying Yorktown confining unit.

The quality of ground water (represented by spring discharge) near Yorktown Battlefield depends on the aquifer from which the water discharges and the location of the spring. Concentrations of major ions were lower in water discharging from the Columbia aquifer than from the Cornwallis Cave aquifer. Concentrations of bicarbonate ions in water from two springs discharging from the Columbia aquifer, for example, were 0 and 6 milligrams per liter (mg/L); concentrations in water from 12 springs discharging from the Cornwallis Cave aquifer ranged from 133 to 410 mg/L. The primary source of high concentrations of bicarbonate ions in the Cornwallis Cave aquifer likely is the dissolution of aragonite in shell material in the aquifer. Concentrations of bicarbonate ions in water discharging from the Cornwallis Cave aquifer in the York River Basin generally were higher than concentrations in discharge in the James River Basin. The higher concentrations in discharge in the York River Basin can result from less precipitation of calcite from water in the York River Basin where flow paths are shorter and ground water likely is younger than in the James River Basin.

Concentrations of bicarbonate ion control the buffering of ground water. The pH of water from two springs discharging from the Columbia aquifer (low bicarbonate concentrations) was 4.5 and 5.1, whereas that of water from springs discharging from the Cornwallis Cave aquifer (high bicarbonate concentrations) ranged from 7.0 to 7.8. The pH, in turn, affects other aspects of ground-water quality; for example, aluminum concentrations of water from two springs discharging from the Columbia aquifer were 410 and 140 micrograms per liter (μg/L), whereas concentrations in water from springs discharging from the Cornwallis Cave aquifer were less than the 15 μg/L minimum reporting limit.

The preceding analysis was based primarily on surface information (soils, outcrops, topography, and springs) at the battlefield and on subsurface information from wells and boreholes surrounding the battlefield. Because of the complex geology and the lack of appropriate wells and other sources of subsurface information at the battlefield, future research would necessitate the installation of more wells throughout the battlefield to provide additional geologic and other information. Future research on the shallow aquifer system could include (1) continued development of the geohydrologic framework; (2) monitoring of ground-water levels and quality, rates of spring discharge, streamflow, and stream-water quality; and (3) evaluation of the connection between the shallow aquifer system and the streams, wetlands, and associated habitats. The framework provides the conceptualization of the physical constraints that control the flow of ground water and transport of contaminants. Monitoring provides essential information for evaluating long- and short-term trends in the hydrology and water quality of the shallow aquifer system, streams, and wetlands. A better understanding of the connection between the shallow aquifer system and the streams, wetlands, and associated habitats is needed to protect and manage the quantity and quality of water in these systems.

INTRODUCTION

Colonial National Historical Park (CNHP) is a 9,327-acre (3,775-hectare) part of the National Park System located in north-central York County, Virginia (fig. 1). The park preserves the historic resources of Jamestown Island, the site of the first permanent English settlement in North America, and Yorktown Battlefield, the location of the culminating battle of the American Revolutionary War. The 23-mi-long (37-km) Colonial National Historical Parkway connects Jamestown Island and Yorktown Battlefield. The park also preserves the streams and wetlands within these areas. The streams and wetlands at Yorktown Battlefield provide (1) critical habitat for rare, threatened, and endangered species, (2) nurseries for numerous commercial and recreational sport fishery species, and (3) opportunities for observation, education, and recreational fishing.

Numerous documents contain guidelines for managing activities and the historical, cultural, and natural resources of the park. The Water Resource Management Plan (Center for Coastal Management and Policy and National Park Service, 1994) contains guidelines for managing the water resources of the park. The plan discusses (1) available information on

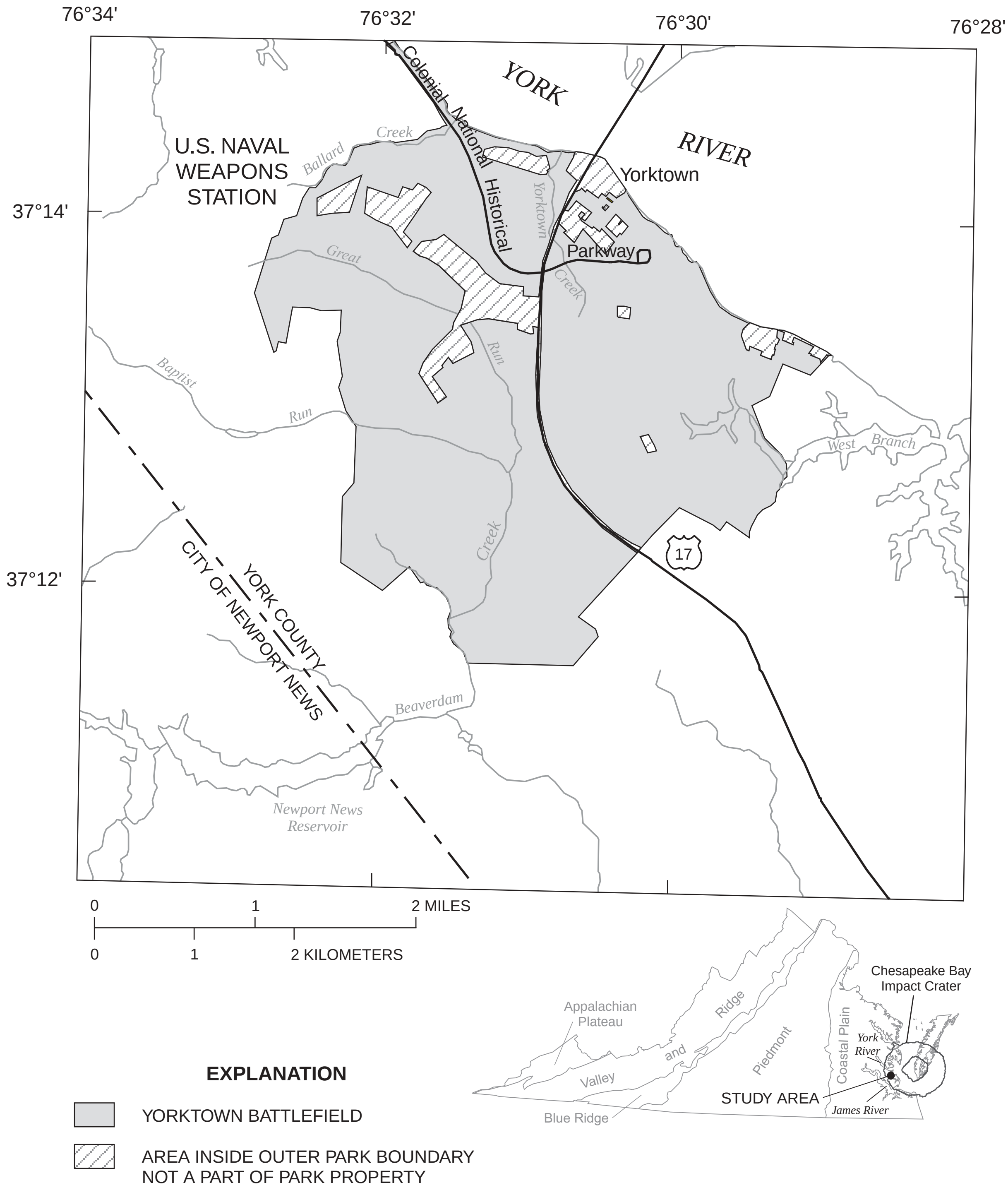


Figure 1. Location of study area near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia.

the water resources and water-dependent environments, (2) major water-resource management issues, and (3) the need for inventorying, monitoring, researching, and managing the water resources of the park. The plan identifies a general need to better understand the hydrology and aquatic resources of the park, recognizes the hydraulic connection between the park and surrounding areas, and identifies a specific need to delineate and characterize the shallow aquifer system.

Ground water is important to the park partly because ground-water discharge supplies a large part of the freshwater flow to streams and can be an important source of water to wetlands. Consequently, ground water is an important potential pathway for contaminant transport from land surface to streams and wetlands. Because the shallow aquifers (aquifers generally shallower than 150 ft) have a better hydraulic connection with streams and wetlands than the deep aquifers (aquifers generally deeper than 150 ft), the shallow aquifers are the primary sources of ground-water discharge. Therefore, the hydrology and water quality of the shallow aquifer system can substantially affect the surface-water resources, wetlands, and associated habitats of the park and surrounding areas.

In 1999, the U.S. Geological Survey (USGS), in cooperation with the National Park Service (NPS), began a study of the shallow aquifer system near Yorktown Battlefield. The primary objective of this study was to provide a preliminary delineation and characterization of the shallow aquifer system near Yorktown Battlefield and to identify additional research on the shallow ground-water resources that is needed for the management of park resources.

Purpose and Scope

The purpose of this report is to provide (1) a preliminary delineation of the aquifers and confining units and (2) a general characterization of the hydrology and water quality of the shallow aquifer system near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia (fig. 1). The shallow aquifer system described in this report includes those aquifers and confining units that extend from land surface to and including the upper part of the Yorktown-Eastover aquifer. Descriptions of the aquifers and confining units and the hydrology of the shallow aquifer system are based primarily on available geologic and hydrologic information. The water quality of the shallow aquifer system is characterized by use of water-quality data from samples collected from springs and seeps during this study. The report also identifies additional research needed on the shallow aquifer system and its effects on streams, wetlands, and associated habitats.

Previous Investigations

Previous investigations of ground water near Yorktown Battlefield generally have emphasized areas outside of the battlefield. Early investigations evaluated the ground-water resources of the entire Coastal Plain of Virginia or of the York-James Peninsula part of the Coastal Plain and generally focused on the deep aquifer system. Sanford (1913) first described the ground-water resources of the Coastal Plain of Virginia, providing drillers' logs, well-construction records, and ground-water-quality data. Cederstrom (1957) described the ground-water resources of the York-James Peninsula, providing additional information for the local area. The Virginia State Water Control Board (1973) described the geohydrology and water quality of the "upper and principal artesian systems" of the peninsula. Harsh (1980) studied the deep aquifer system of James City County, which is located west of the battlefield. Meng and Harsh (1988) delineated nine regional aquifers throughout the Coastal Plain by correlating geophysical logs, drillers' logs, and lithologic logs as a part of the USGS Regional Aquifer-System Analysis (RASA) Program. Harsh and Laczniak (1990) used a digital, finite-difference model to simulate ground-water flow throughout the Coastal Plain, also as part of the RASA Program. Laczniak and Meng (1988) used a digital, finite-difference model to simulate ground-water flow near the York-James Peninsula.

Recent studies have focused on the hydrology and quality of the shallow ground water near Yorktown Battlefield. Brockman and Richardson (1992) and Richardson and Brockman (1992) described the shallow ground-water hydrology and quality of York County. Brockman and others (1997) described the shallow ground-water hydrology of the adjacent U.S. Naval Weapons Station Yorktown, in north-central York County to the west of Yorktown Battlefield. In 2001, the USGS completed a study of the apparent age and behavior of ground water in the shallow aquifer system of the Naval Weapons Station (Nelms and others, 2001).

Johnson and others (1998) and Powars and Bruce (1999) described the effects of the impact of a comet or meteorite into sediments beneath what is now Chesapeake Bay. This impact occurred about 35 million years ago and formed the approximately 56-mi (90-km)-wide Chesapeake Bay impact crater (fig. 1) containing disturbed and redeposited sediments. Although the depth of the top of the redeposited sediments beneath Yorktown Battlefield is several hundred feet, the presence of the impact crater beneath the battlefield possibly affects the composition and stratigraphy of shallow sediments.

Additional studies have evaluated the shallow ground-water hydrology at hazardous waste sites at the Naval Weapons Station and were conducted under the Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Superfund Amendments Reauthorization Act of 1986 (SARA) (Dames and Moore, 1986, 1988; Baker Environmental, Inc. and Roy F. Weston, Inc., 1993; Baker Environmental, Inc., 1995). Consequently, these investigations focused on the assessment and remediation of potential surface-water and (or) ground-water contamination.

Site-specific studies of the ground-water hydrology of Yorktown Battlefield are limited. Focazio (1997) identified 36 springs and seeps near the battlefield. Water samples were collected from each spring and analyzed in the field for selected properties in May and August 1996. Samples from 10 of the springs were analyzed for chlorofluorocarbon concentrations to determine the “apparent age” of the ground water. More recently, the NPS and Virginia Institute of Marine Sciences installed 18 shallow wells at Yorktown Battlefield to evaluate potential contamination from sources outside of the battlefield (MacIntyre and others, 1998). Samples were collected quarterly and analyzed for a limited number of water-quality properties; samples from five wells were analyzed for selected organic compounds.

Description of Study Area

Yorktown Battlefield is located on the York-James Peninsula between the York River and James River estuaries in the Coastal Plain of Virginia (fig. 1). It covers approximately 4,300 acres (1,740 hectares) in north-central York County and is adjacent to the City of Yorktown.

Physiography

The physiography near Yorktown Battlefield affects the shallow ground-water hydrology through associated effects on geology, stream-valley incisement, and the locations of recharge and discharge areas. Different terraces commonly reflect the different formations across the area. Stream valleys are incised differently depending on location and elevation, greatly affecting the hydraulic connection between the shallow aquifer system and surface-water bodies and wetlands. This connection affects the location of recharge and discharge areas.

Land surface is characterized by five level to gently sloping terraces at progressively lower elevations (Lackey Plain, Grove Plain, Grafton Plain, Huntington flat, and Hornsbyville flat) (Johnson, 1972; Johnson and others, 1993) (fig. 2). Scarps separate these terraces. Lackey Plain is located west of the battlefield and ranges from 80 to 90 ft (24.5 to 27.5 m) above sea level. An indistinct boundary separates Lackey Plain from Grove Plain. Grove Plain covers a large part of the northwestern part of the battlefield and ranges from 70 to 75 ft (21.0 to 23.0 m) above sea level. Camp Peary scarp separates Lackey and Grove Plains from land at lower elevation along the York River. Lee Hall scarp separates Grove Plain from Grafton Plain to the southeast. Grafton Plain covers a large part of the central and eastern parts of the battlefield and ranges from 48 to 60 ft (14.5 to 18.0 m) above sea level. Kingsmill scarp separates Grafton Plain from Huntington flat to the south; Suffolk scarp separates Grafton Plain from Hornsbyville flat to the east. Huntington flat is located in the Beaverdam Creek valley in the south-central part of the battlefield and ranges from 30 to 45 ft (9.0 to 13.5 m) above sea level. Hornsbyville flat covers a 0.5-mi-wide (0.8-km) band east of the battlefield and is 25 to 30 ft (7.5 to 9.0 m) above sea level.

Stream valleys incise these terraces, causing additional local changes in elevation. In the York River Basin, the valleys of Ballard Creek, Yorktown Creek, West Branch, and their tributaries are short and deeply incised with steep walls (fig. 3A). The valley bottoms generally are less than 10 ft (3 m) above sea level along much of their length and slope gently toward the York

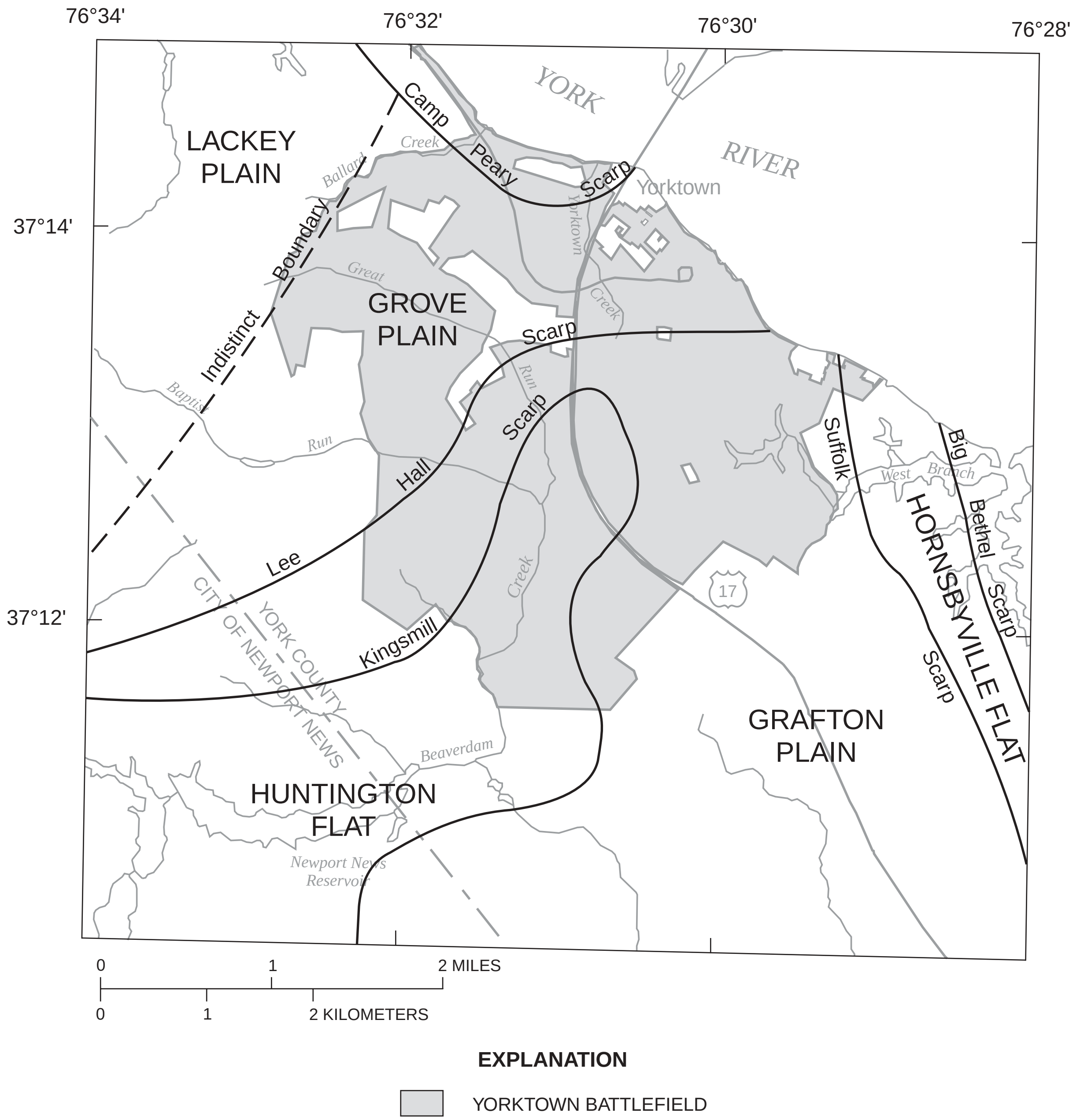


Figure 2. General location of scarps and terraces near the Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia.

River. Upland terraces that separate the valleys tend to be narrow. The lower parts of the streams in these valleys are tidal.

Valleys in the James River Basin are longer than those in the York River Basin and include the valleys of Beaverdam Creek, named tributaries Baptist Run and Great Run, and numerous unnamed tributaries (fig. 1). Great Run and Baptist Run flow to the east and southeast to form Beaverdam Creek. Beaverdam Creek flows south across the southern boundary of Yorktown Battlefield. These valleys are less deeply incised and have more gently sloping walls and broader valley bottoms than those in the York River Basin (fig. 3B). The elevation of the valleys decreases from more than 50 ft (15 m) above sea level at their upstream ends to less than 20 ft (6 m) above sea level at the lower end of Beaverdam Creek. Broad upland terraces separate these valleys. The streams in these valleys are nontidal throughout the battlefield.

Land Cover

Land cover affects the hydrology and quality of shallow ground water in various ways. Fields and forests are pervious surfaces that enhance ground-water recharge; buildings, roads, and other paved areas are impervious surfaces that limit recharge. Wetlands can be areas of appreciable ground-water recharge and discharge. Materials on land surface and in the subsurface can affect the ground-water quality.

Large fields and forests are the predominant land cover at Yorktown Battlefield (fig. 4). Upland grass fields are mowed and maintained because of their historical and cultural significance as battlefields and encampments. The remaining upland areas are predominantly forested. Stream valleys are predominantly forested wetlands except for the lower parts of the valleys in the York River Basin, which are non-forested wetlands. Sinkhole wetlands are the only wetlands in upland areas. The remaining areas consist of roads, parking areas, and buildings for a visitor center, offices, and maintenance facilities.

Land cover is diverse outside the boundaries of Yorktown Battlefield. Residential and commercial areas are interspersed inside the outer boundary but are not a part of battlefield property (fig. 1). The City of Yorktown and the York River are north of the battlefield. The U.S. Naval Weapons Station Yorktown lies northwest of the battlefield and consists of a mixture of forested areas and areas developed for military purposes. Areas of contamination from hazardous materials have been identified at the weapons station (Dames and Moore, 1986, 1988; Baker Environmental, Inc. and Roy F. Weston, Inc., 1993; Baker Environmental, Inc., 1995). A large part of the area southwest and south of the battlefield is a park belonging to the City of Newport News that is primarily forested. Small residential and commercial areas are scattered through forested areas to the west of the battlefield, and mixed land cover lies east of the battlefield.

Geology

The lithology and the vertical and lateral extent of geologic units form the physical framework of the shallow aquifer system. The following description of the lithology, inferred depositional environments, and extent of the shallow formations is based primarily on summaries from previous investigations near Yorktown Battlefield by Johnson (1972), Brockman and Richardson (1992), and Brockman and others (1997). The depth of shallow sediments described in this report generally is less than 150 ft (30 m).

The shallow geology of York County consists of nine formally named formations of early Miocene to late Pleistocene age and undifferentiated alluvial and marsh deposits of Holocene age. One of these formations (the Yorktown Formation) is formally divided into four members. Some of these geologic units, however, are absent and others are too deep to be of importance to the shallow aquifer system near the battlefield. Units that form parts of the shallow aquifer system near Yorktown Battlefield in ascending stratigraphic order include the Rushmere, Morgarts Beach, and Moore House Members of the Yorktown Formation; the Sedley Formation; the Bacons Castle Formation; the Windsor Formation; the Chuckatuck Formation; the Shirley Formation; the Tabb Formation; and modern alluvial and marsh deposits (fig. 5).

Although faults may be present and the thickness and composition of shallow sediments can vary near the battlefield because of the Chesapeake Bay impact crater (Johnson and others, 1998; Powars and Bruce, 1999), specific effects on the shallow sediments have not been studied at the battlefield. Consequently, potential effects of the impact crater on the geology and hydrology near Yorktown Battlefield are not discussed in this report.

(A)

(B)

Figure 3. Deep valley and steep valley wall of the York River Basin *(A)* and a less deeply incised valley and more gently sloping valley wall of the James River Basin *(B)* near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia.

Figure 4. Fields maintained for their historical significance, forests, and the visitor center at Yorktown Battlefield, Colonial National Park at Yorktown, Virginia (view looking northwest).

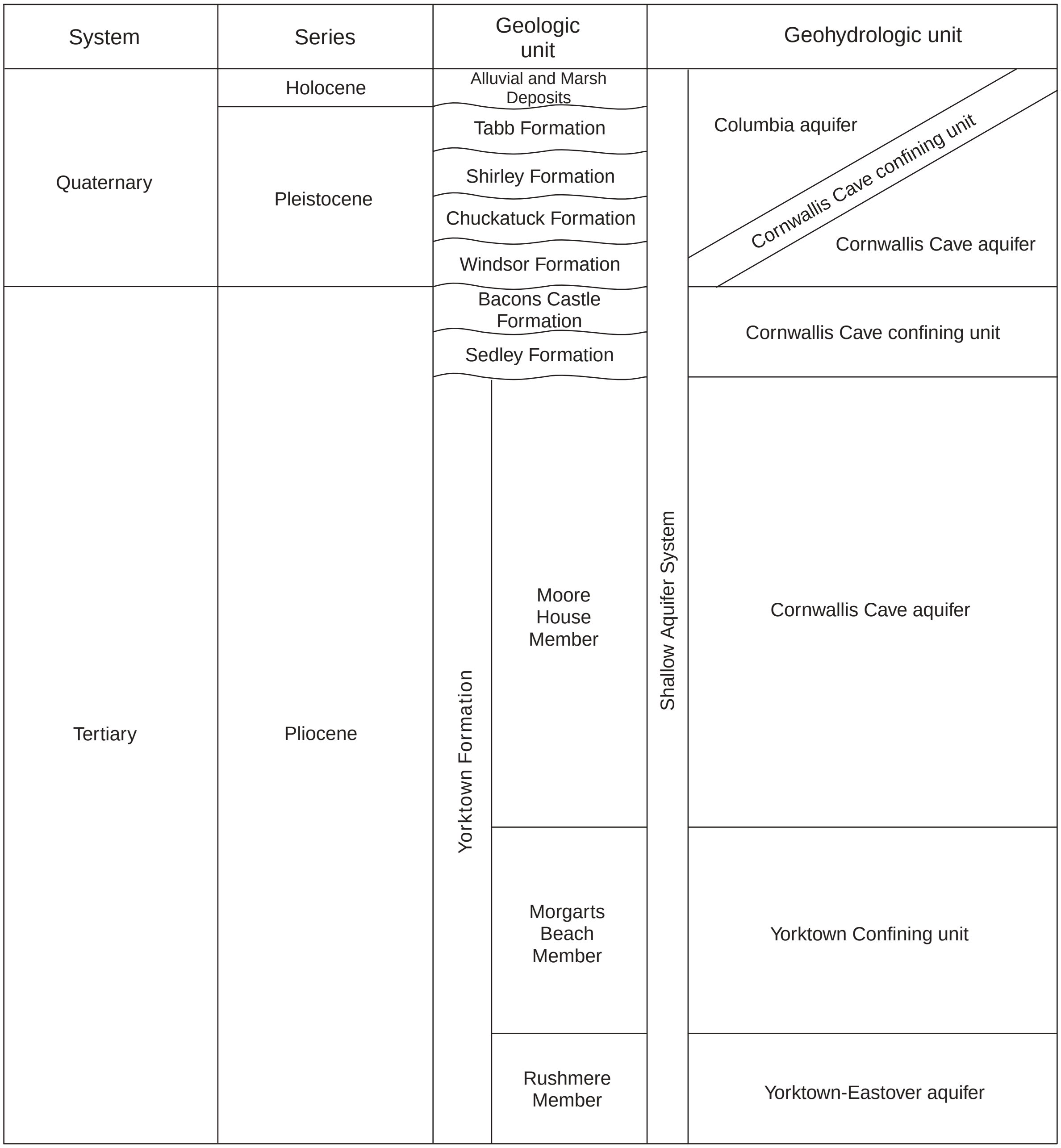


Figure 5. Relation between geology and geohydrologic units near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia.

The Rushmere Member of the Yorktown Formation consists of shelly, fine-grained quartz sand and sandy shell deposited on an open-marine shallow shelf. It is laterally continuous and is below land surface near the battlefield. The Morgarts Beach Member of the Yorktown Formation contains clay, silt, and fine-grained sand deposited in a wide lagoon behind a barrier bar. It is laterally continuous beneath the battlefield and is below land surface except where it is exposed near the northwest corner of the battlefield along Ballard Creek and the York River. The Moore House Member of the Yorktown Formation contains fine-grained sand, shell hash, and bioclastic sand deposited during a marine-regressive period in a progressively shallowing sea. In the upper part of the Moore House Member, much of the shell has weathered from the sediment leaving fine-grained sand, silt, and clay. The elevation of the contact between the weathered and shelly parts of the unit varies by more than 10 ft (3 m) in a lateral distance of less than 20 ft (6 m). The Moore House Member has been eroded by streams but likely is present throughout the battlefield except where the Morgarts Beach Member is at land surface along Ballard Creek and the York River.

The Sedley Formation unconformably overlies the Moore House Member of the Yorktown Formation beneath the Lackey Plain (Brockman and others, 1997). The Sedley Formation consists of sandy-clayey silt with or without sand lenses deposited in tidal streams and estuaries. The Bacons Castle Formation unconformably overlies the Sedley Formation. It consists of clayey silt and silty fine-grained sand. The Sedley and Bacons Castle Formations have been eroded in places and are absent beneath Yorktown Battlefield (C. Richard Berquist, Virginia Division of Mineral Resources, oral commun., 2000).

The remaining formations are terrace, alluvial, and marsh deposits; each is at land surface at different locations across the battlefield. Although the lateral extent of each formation commonly is associated with a particular terrace (Johnson, 1972), the associated formation is not necessarily present everywhere beneath the respective terrace (C. Richard Berquist, Virginia Division of Mineral Resources, oral commun., 2000). In general, these formations consist of coarse-grained sediments at their base and overlying fine-grained sediment. The Windsor Formation is present primarily to the west beneath the Lackey and Grove Plains. It consists of sand, gravel, silt, and clay deposited in estuarine or bay environments. The Chuckatuck Formation is present primarily beneath the Grafton Plain. It consists of sand, silt, clay, and small amounts of peat deposited in a bay environment. The Shirley Formation primarily underlies the Huntington flat and low areas along the York River. It consists of gravel, sand, silt, clay, and peat deposited in riverine and estuarine environments. In the study area, the Tabb Formation underlies areas adjacent to the York and James Rivers. It consists of sand, silt, clay, and peat deposited in estuaries and rivers and on barrier islands, beach ridges, flood plains, and point bars. Holocene alluvial and marsh deposits are present primarily in the river valleys and consist of clay, silt, and sand. Deposition still occurs in stream channels and flood plains.

Soils

Soil permeability affects the rate at which precipitation infiltrates the soil and percolates downward to recharge the shallow aquifer system. Low soil permeability impedes infiltration, percolation, and ground-water recharge and enhances surface runoff; high soil permeability enhances infiltration, percolation, and ground-water recharge. Recharge likely is higher where the permeability of soils remains high to greater depths.

Soil composition varies across the battlefield, generally depending on the physiography and proximity to the York River (Hodges and others, 1981). Soils in the uplands are largely of the Slagle Series, a moderately well drained, fine sandy loam (table 1). In the southeastern part of the battlefield, upland soils also include silt loams of the Newflat and Peawick Series. The Newflat Series is somewhat poorly drained; the Peawick Series is moderately well drained. Along the York River, upland soils include Bojac sandy loam and Uchee loamy fine sand. Both series are well drained. Valley slopes generally are of the Cravens-Uchee and Emporia complexes. The Cravens-Uchee complex is a moderately well drained, fine sandy loam; the Emporia complex is a well-drained, fine sandy loam. The flood plains generally contain soils of the Johnston Series, a very poorly drained silt loam.

Except for the Bojac Series, the permeability of the soils in the uplands decreases with depth (table 1). The permeability of the Slagle Series, the primary upland soil, decreases from a range of 2 to 6 (in/h (50 to 150(mm/h) at depths of 0 to 9 in. (0 to 230 mm) to 0.06 to 0.6 in/h (1.5 to 15 mm/h) below a depth of 25

Table 1. Major soils and selected soil characteristics near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia (modified from Hodges and others, 1981)

[>, greater than; <, less than]

Soil name	Texture	Extent	Drainage class	Depth interval (inches)	Permeability (inches infiltrating per hour)
Bojac	Sandy loam	Uplands near the York River	Well drained	0-25 25-53 53-71	2.0-6.0 2.0-6.0 >6.0
Cravens	Fine sandy loam	Upland ridges and side slopes	Moderately well drained	0-9 9-30	0.6-2.0 0.06-0.2
Emporia	Fine sandy loam	Valley slopes	Well drained	0-13 13-37 37-38	2.0-6.0 0.2-2.0 0.02-0.6
Johnston	Silt loam	Flood plains	Very poorly drained	0-8 8-49 49-60	2.0-6.0 0.6-2.0 0.6-2.0
Newflat	Silt loam	Upland flats	Somewhat poorly drained	0-8 8-11 11-80	0.6-2.0 0.2-0.6 <0.06
Peawick	Silt loam	Upland flats	Moderately well drained	0-7 7-99	0.6-2.0 <0.06
Slagle	Fine sand loam	Upland flats	Moderately well drained	0-9 9-25 25-60	2.0-6.0 0.6-2.0 0.06-0.6
Uchee	Loamy fine sand	Upland ridges and side slopes	Well drained	0-24 24-36 36-56	6.0-20 0.6-2.0 0.2-0.6

in. (640 mm). The permeability of the upland soils is least for the Newflat and Peawick Series; permeability of these soil series decreases from 0.6 to 2.0 in/h (15 to 50 mm/h) at the surface to less than 0.06 in/h (1.5 mm/h) more than 7 to 9 in. (180 to 230 mm) below land surface.

Hydrology

The shallow aquifer and surface-water systems near Yorktown Battlefield are hydraulically interconnected and hydraulically connect the battlefield and surrounding areas. Precipitation that falls on land surface either flows to streams in various ways to create surface runoff, infiltrates the soils, or collects in sinkholes and other depressions in the land surface. Surface runoff supplies a large part of the streamflow for periods during and following precipitation (stormflow periods) but eventually ceases to be a source of water to streams (base-flow periods). Base flow is sustained by ground-water discharge. Water that infiltrates the soil either discharges to the atmosphere through evaporation and plant transpiration (evapotranspiration) or percolates downward to recharge the shallow aquifer system. Water that collects in depressions can form seasonal wetlands. This water eventually discharges through evapotranspiration, slowly discharges to streams, or recharges the shallow aquifer system. Thus, precipitation is the source of most ground-water recharge to the shallow aquifer system near Yorktown Battlefield. Ground-water recharge flows vertically and laterally through the shallow aquifer system toward low areas and eventually discharges to ditches, seeps, springs, streams, and wetlands. Ground-water discharge provides part of the streamflow during stormflow periods and all of the natural streamflow during base-flow periods.

The ground-water system beneath Yorktown Battlefield consists of interlayered aquifers and confining units that extend from near land surface to a depth of about 1,800 ft (550 m) (Meng and Harsh, 1988). Aquifers contain sandy and shelly sediments through which water flows readily; confining units contain silty and clayey sediments that inhibit the flow of water. The thickness, composition, and hydraulic characteristics of the aquifers and confining units vary vertically and laterally. The aquifer system can be divided into a deep and a shallow system. In general, the deep aquifer system is poorly connected to the shallow aquifer system, surface-water bodies, or wetlands; the shallow aquifer system generally is well connected to the surface-water bodies and wetlands. Based on the degree of hydraulic connection between the aquifers and surface-water bodies and wetlands, the shallow aquifer system described in this report extends from near land surface to the upper part of the Yorktown-Eastover aquifer. This delineation is based on the depth of the aquifers and the similar response of ground-water levels in this part of the system (White and Powell, 2000).

Ground-water discharge can provide a major part of the streamflow near Yorktown Battlefield. Richardson (1994) determined that ground-water discharge provides 47 to 79 percent of the annual flow in streams in the Coastal Plain of Virginia. This discharge can be through seeps, springs, or direct discharge to ditches, streambeds, and wetlands. Seeps are areas of diffuse discharge and are common near the battlefield, particularly in wetlands and where flow originates in streams (fig. 6A). Springs are areas of focused discharge and commonly are located near the base of valley walls and in streambeds near the battlefield; multiple focused discharge points form many of the springs (fig. 6B). Many of the springs appear to occur where pathways of focused flow in the subsurface intersect land surface. Near land surface, many of these pathways form holes in silt, clay, peat, and shell. Although the origin of these pathways is not certain, many appear to be holes left from decayed tree roots; some springs flow from the base of trees and some springs having multiple discharges appear to be located where trees have fallen and left depressions in land surface.

Processes Affecting Ground-Water Quality

Major anions (negatively charged ions) and cations (positively charged ions) are the dominant naturally occurring constituents in water and can be used to differentiate sources of ground water and to identify ground-water flow paths. The anions include bicarbonate (HCO_3^-), carbonate (CO^{-2}), chloride (Cl), and sulfate (SO_4^{-2}). The cations include calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^+), and potassium (K^+). Other constituents used to characterize ground-water quality include iron (Fe), manganese (Mn), and dissolved silica (SiO_2), which also can occur in high concentrations. Concentrations of the nutrients nitrogen and phosphorus that are elevated above background levels contribute to increased growth of algae in surface-water bodies and indicate potential contamination from anthropogenic sources.

Major ions and nutrients are derived from a combination of natural and anthropogenic sources. Precipitation that recharges the ground water contributes low concentrations of many dissolved constituents. As the precipitation infiltrates the soil and flows through the aquifers and confining units, it reacts with the shell and rock material to increase concentrations of dissolved constituents. The amount of major ions that dissolves in the ground water depends on the minerals in the shell and rock material; dissolution typically increases as contact time between the water and the shell and rock material increases. Thus, shallow, younger water typically contains lower concentrations of major ions than deeper, older water. Anthropogenic sources also can be direct sources of major ions and can affect the natural reactions. Thus, land use in recharge areas can appreciably affect ground-water quality.

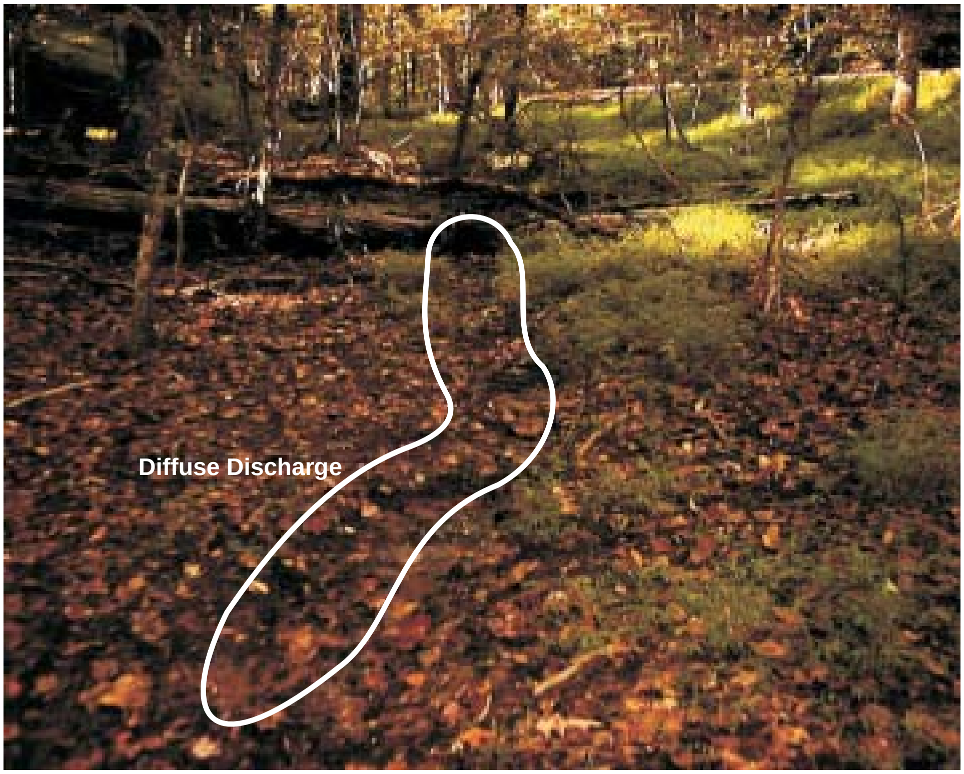
Organic material and some types of rocks are common natural sources of nitrogen and phosphorus. Rocks have not been identified as major sources of these nutrients to shallow ground water near Yorktown Battlefield. Fertilizers and human and animal waste, along with atmospheric deposition of nutrients produced by anthropogenic sources, are common sources of nitrogen and phosphorus.

One of the primary sources of major ions in the shallow aquifer system near Yorktown Battlefield is the dissolution of shell material, which contains calcium carbonate ($CaCO_3$) in the forms of the minerals aragonite and calcite. The reaction for the dissolution of shell material is

$$CaCO_3 \leftrightarrow Ca^{+2} + CO_3^{-2},$$

Dissolution continues until the ions become saturated with respect to the mineral that is dissolving. Dissolution of aragonite, which is more soluble than calcite, can result in higher concentrations of calcium and carbonate in the water than dissolution of calcite (Drever, 1988). Because concentrations of calcium and carbonate derived from the dissolution of aragonite can exceed calcite solubility (supersaturation), calcite can

(A)



(B)

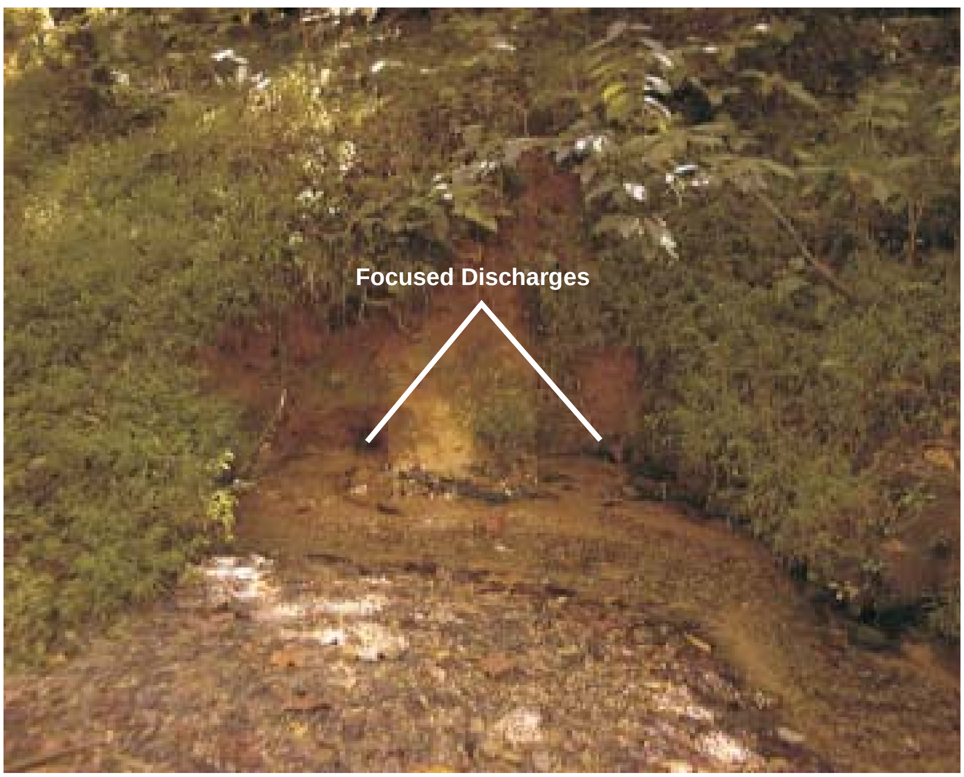


Figure 6. Diffuse discharge of a seep *(A)* and the focused discharge of a spring *(B)* near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia.

precipitate in aquifers and streambeds. Calcium and carbonate, however, commonly remain supersaturated with respect to calcite in many aquifers (Drever, 1988).

When acid is present, hydrogen ion (H^+) combines with carbonate ion to form bicarbonate ion by the reaction

$$H^+ + CO_3^{-2} \leftrightarrow HCO_3^-,$$

Because acid reduces the concentration of carbonate ion in solution, the amount of aragonite or calcite that can dissolve increases in the presence of acid. Common sources of acid include precipitation, hydrolysis of carbon dioxide, certain land uses, and geochemical reactions between water and rocks. Both of these reactions are reversible, include the carbonate ion, and are controlled by reaction equilibrium constants; therefore, concentrations of hydrogen, calcium, carbonate, and bicarbonate ions collectively control the dissolution and precipitation of aragonite and calcite.

Iron and manganese concentrations in water commonly are affected by oxidation-reduction reactions. When concentrations of dissolved oxygen are sufficiently greater than 0 mg/L in water, iron and manganese occur primarily as oxidized species that commonly have a low solubility and are in low concentrations in water. When concentrations of dissolved oxygen are near 0 mg/L, iron and manganese more likely occur as reduced species. Reduced species tend to have a high solubility and, therefore, can occur in high concentrations. The solubility of iron and manganese also increases as the pH of the water decreases (Hem, 1985).

Minerals that primarily contain aluminum and silica (aluminosilicates) are major constituents in many rocks. Diagenesis (chemical and physical weathering) of these minerals generally produces other aluminosilicate minerals and can be a major source of dissolved silica, aluminum, iron, manganese, and other cations in water. Because diagenesis tends to be slow, concentrations of constituents derived from diagenesis commonly are low in shallow ground water near recharge areas.

Quartz, which is a common silicate mineral in aquifers and confining units, is a common source of dissolved silica because it dissolves quickly. At the pH of most natural waters (5.5 to 8.5), quartz dissolves until dissolved silica concentrations reach the saturation concentration for quartz of about 6 mg/L (Krauskopf, 1979). Concentrations of silica above 6 mg/L must, therefore, be derived from other sources.

Nitrogen can be present as several species in ground-water systems (Mitsch and Gosselink, 1993). Dissolved organic nitrogen is present in organic material dissolved in water. When bacteria decompose the organic material, the nitrogen is released, or mineralized, to form ammonia (NH_3). In water, ammonia hydrolyzes to form ammonium hydroxide (NH_4OH) by the reaction

$$NH_3 + H_2O \rightarrow NH_4OH.$$

In the normal range of pH in ground water (5.5 to 8.5), ammonium hydroxide readily ionizes to form ammonium and hydroxyl ions (NH_3^+ and OH^-). Ammonium ion is readily immobilized by cation exchange onto silt and clay minerals; and ammonia concentrations typically are low in ground water, partly because of the effects of cation exchange.

Where the dissolved-oxygen concentration in the ground water is near 0 mg/L, ammonium typically remains as ammonium. Where dissolved oxygen is sufficiently higher than 0 mg/L, ammonium oxidizes (nitrifies) through a series of reactions mediated by bacteria to form nitrite ion (NO_2^-), then to form nitrate ion (NO_3^-) by the reactions

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O + \text{energy}$$

and

$$NO_2^- + \tfrac{1}{2}\, O_2 \rightarrow NO_3^- + \text{energy}.$$

Nitrate is extremely soluble, and, therefore, is readily transported through ground water. Where dissolved oxygen becomes sufficiently depleted and nitrate is present, the nitrate can be reduced (denitrified) by the bacteria to form nitrogen gas (N_2).

Dissolved phosphorus commonly occurs at low concentrations in ground water because it readily sorbs to soil and aquifer material. Phosphorus is present in organic material dissolved in ground water and is released as the organic material decomposes. Phosphorus then hydrolyzes through a series of steps to form orthophosphate (PO_4^{-3}). Phosphorus concentrations commonly are reported as dissolved phosphorus (includes all forms of dissolved phosphorus) or orthophosphorus.

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METHODS

Aquifers and confining units that make up the shallow aquifer system were delineated to develop a geohydrologic framework by analyzing borehole geophysical logs (electric and gamma), drillers' logs, and lithologic logs from USGS files and from boreholes drilled by the Virginia Division of Mineral Resources (C. Richard Berquist, Virginia Division of Mineral Resources, unpublished data, 1999). A published geologic map (Johnson, 1972), a preliminary revised geologic map (C. Richard Berquist, Virginia Division of Mineral Resources, written commun., 2000), and observations of rock outcrops also were used in the analysis. Borehole geophysical logs were the primary basis for the delineation of aquifers and confining units because they provide a more consistent and objective representation of the geologic and hydrologic conditions than drillers' logs and lithologic logs. Only one well (58F64) and one borehole (94342) on the battlefield have geohydrologic information to a sufficient depth for use in the geohydrologic framework; the other wells and boreholes that were used are outside of the battlefield (fig. 7).

The geohydrologic framework presented in this report is based on the frameworks of Brockman and Richardson (1992) and Brockman and others (1997). Major modifications to these frameworks are discussed in this report. This report's framework is presented in (1) two geohydrologic sections, (2) a map of the elevation of the top of the Yorktown confining unit, (3) a map of the elevation of the top of the Yorktown-Eastover aquifer, and (4) a conceptual diagram. Hydraulic information is from slug tests on wells and permeameter tests on cores from the U.S. Naval Weapons Station Yorktown (Brockman and others, 1997).

The water quality of the shallow aquifer system was determined by analyzing 14 water samples collected from springs and seeps throughout Yorktown Battlefield (fig. 7). Springs and seeps were sampled because the goal of the study was to evaluate the "typical" quality of water from comparable sources distributed across the battlefield, and few wells are open to appropriate depths at the battlefield. Existing wells were installed in order to monitor local conditions near sinkhole ponds or possible contamination from surrounding land use. Because the number of samples collected in this study was small, using samples from these wells would limit the ability to evaluate typical water quality.

Springs and seeps were selected from those (1) previously identified by Focazio (1997), (2) contained in a NPS data base, and (3) identified in a field reconnaissance conducted as a part of this study. Springs for which the apparent ground-water age was determined (Focazio, 1997) were included as much as possible. As a part of the field reconnaissance, the specific conductance, pH, and temperature of spring water were measured to compare the general water quality of the springs. Two springs that discharge from the Columbia aquifer were identified and sampled; the remaining 12 springs that were sampled discharge from the Cornwallis Cave aquifer and were selected to represent the ground-water quality across the battlefield. Five of these springs are in the James River Basin; seven are in the York River Basin.

Water samples were collected from springs by pumping water from the main flow with a peristaltic pump. Samples analyzed for dissolved constituents were filtered through 0.45-µm pore-size capsule filters.

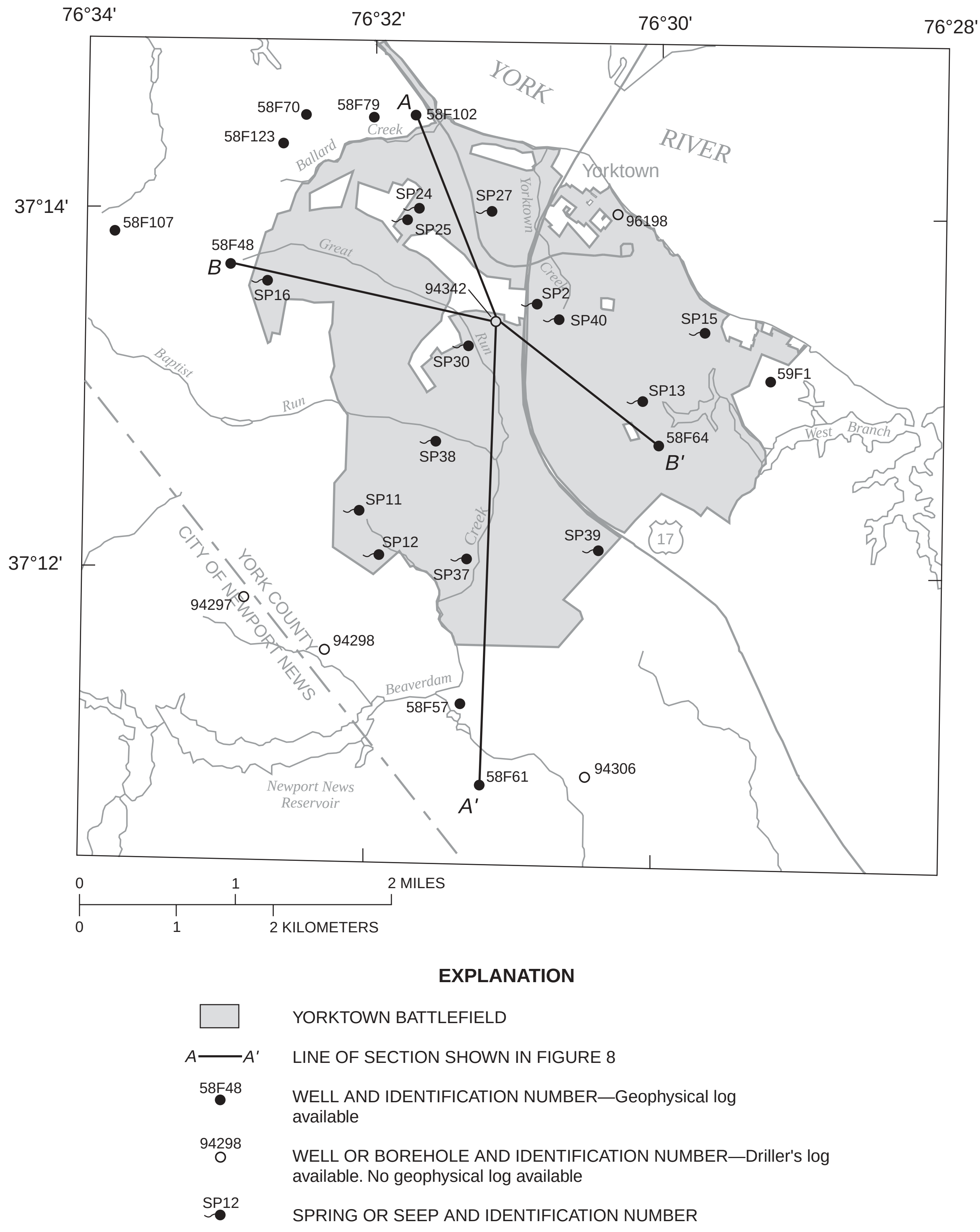


Figure 7. Location of geohydrologic sections, selected wells and boreholes having geohydrologic data, and selected springs having water-quality data near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia.

Samples analyzed for dissolved nutrients were stored in amber plastic bottles and chilled on ice. Samples analyzed for dissolved cations were stored in acid-rinsed plastic bottles and preserved with 1 milliliter of concentrated nitric acid (Wilde and others, 1999). Water temperature, pH, specific conductance, alkalinity, and concentrations of dissolved oxygen of spring water were determined in the field using methods described by Wilde and Radtke (1998). For the determination of water temperature, pH, specific conductance, and concentrations of dissolved oxygen, the meter probe was placed in the center of flow from the spring. Where water discharged as seepage rather than focused flow, the pump intake and probe were placed at the first point where the depth of the water was sufficient (2 to 3 in.) to collect water and submerge the probe. The USGS National Water Quality Laboratory (NWQL) in Arvada, Colo., analyzed samples for concentrations of dissolved major ions, aluminum, silica, and nutrients using methods described by Fishman and Friedman (1989) and Fishman (1993). In some instances, the NWQL reports estimated concentrations for values less than the minimum reporting limit (MRL). Estimated values are identified in table 3 and are included in the discussion but are not identified as estimated values. The spring numbering system used in this report is the same sequential system used by Focazio (1997).

GROUND-WATER HYDROLOGY

Aquifers and confining units provide the physical framework through which water flows in the shallow aquifer system. Brockman and Richardson (1992) define the shallow aquifer system near Yorktown Battlefield as (1) the York County shallow aquifer system (undivided), (2) the Columbia aquifer, (3) the Cornwallis Cave confining unit, (4) the Cornwallis Cave aquifer, (5) the Yorktown confining unit, (6) the Yorktown-Eastover aquifer, and (7) the Eastover-Calvert confining unit. In this report, the shallow aquifer system includes those units that extend from land surface to the upper part of the Yorktown-Eastover aquifer because these units have the best hydraulic connection with the surface-water bodies and wetlands. The lithology of the aquifers and confining units described in this report is based on Brockman and Richardson (1992); the reported hydraulic characteristics are from results of tests on wells and sediment cores at the U.S. Naval Weapons Station Yorktown (Brockman and others, 1997).

Aquifers and Confining Units

The lithology, hydraulic characteristics, and extent of saturated sediments determine how the sediments function in the shallow aquifer system. Sediments that form the upper part of the shallow aquifer system are composed of different terrace deposits at different locations; therefore, the characteristics of the shallow aquifer system vary spatially. Because most of the available geohydrologic information is from wells and boreholes outside of the battlefield, sufficient data are not available to redefine the extent and characteristics of the geohydrologic units beneath the battlefield. Consequently, the extent and characteristics of these units is presented on the basis of the extent and characteristics of the terrace deposits.

York County shallow aquifer system (undivided)

Brockman and Richardson (1992) indicate that the upper part of the shallow aquifer system near Yorktown Battlefield consists of the York County shallow aquifer system (undivided). This unit was delineated as a single unconfined aquifer that includes sediments that commonly form the Columbia aquifer, the Cornwallis Cave confining unit, and the Cornwallis Cave aquifer. These units were grouped as a single aquifer near Yorktown Battlefield because sediments that commonly form the Columbia aquifer and Cornwallis Cave confining unit were not saturated at well 58F64 (fig. 8 and table 2) (Allen R. Brockman, formerly of the U.S. Geological Survey, oral commun., 2000). These sediments, however, can be locally saturated and locally important hydrologic units. Consequently, the York County shallow aquifer system (undivided) is not delineated in this report; the Columbia aquifer and Cornwallis Cave confining unit are delineated on the basis of the composition of their sediments and the function of these sediments, if saturated. Information is insufficient to determine where these sediments are saturated.

Columbia aquifer

The Columbia aquifer is the unconfined aquifer in sandy sediments of Pleistocene to Holocene age

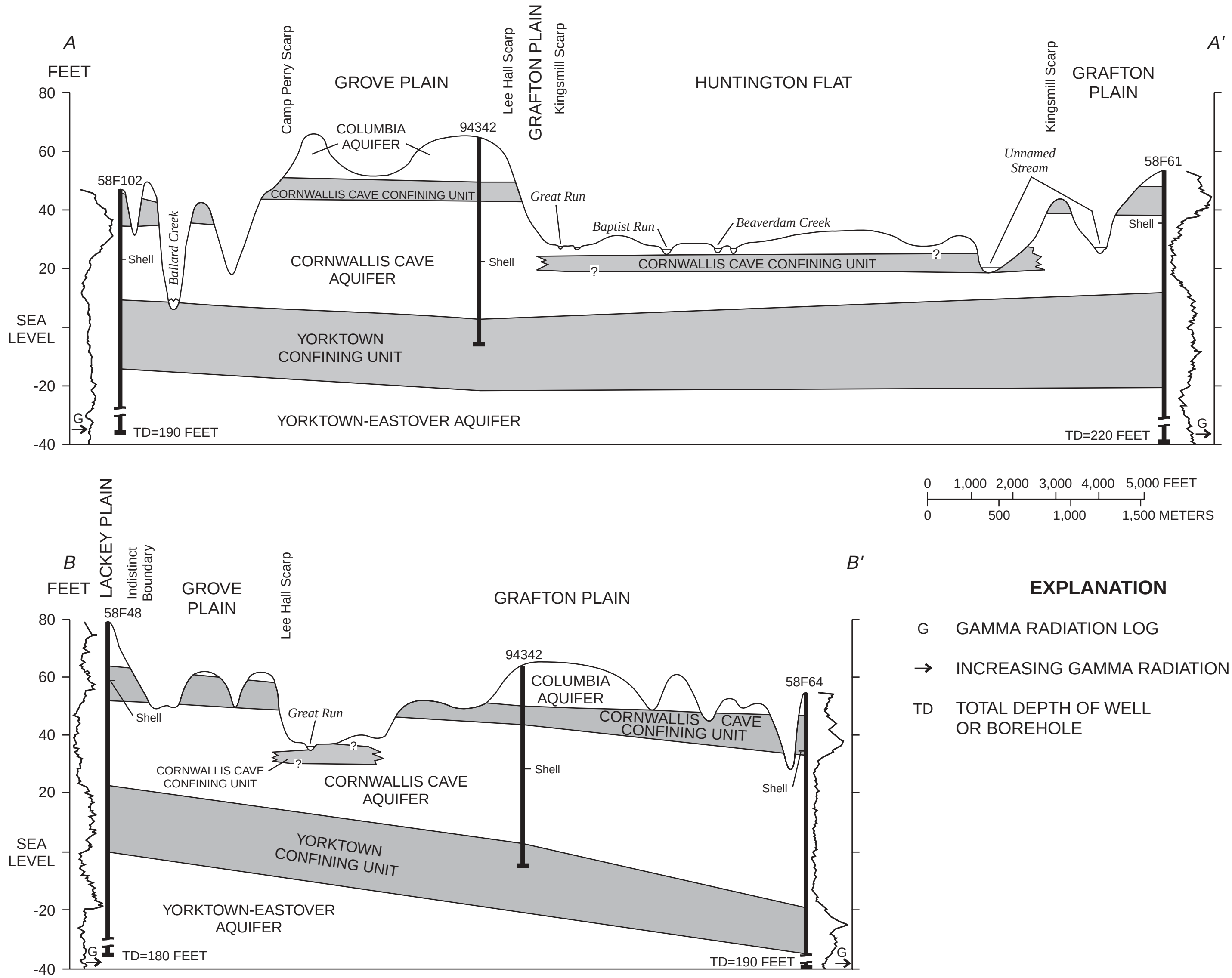


Figure 8. Geohydrologic sections A-A’ and B-B’ near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia. (Locations of sections, wells, and boreholes shown on figure 7).

Table 2. Record of control wells and geohydrologic data near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia

[Latitude and longitude in degrees, minutes, and seconds; elevation in feet, elevation datum is sea level; –, data unavailable]

Well or borehole number	Latitude	Longitude	Land surface elevation	Columbia aquifer, elevation of top	Cornwallis Cave confining unit, elevation of top	Cornwallis Cave aquifer, elevation of top	Yorktown confining unit elevation of top	Yorktown-Eastover aquifer, elevation of top
58F48	37 13 49	76 32 57	80	64	52	24	0	24
58F57	37 11 14	76 31 21	20	–	–	–	-19	–
58F61	37 10 45	76 31 07	55	49	39	15	-19	15
58F64	37 12 50	76 30 05	55	45	33	-19	-35	-19
58F70	37 14 31	76 32 29	72	70	56	10	-6	11
58F79	37 14 32	76 32 03	62	–	55	24	0	24
58F102	37 14 40	76 31 47	48	41	33	13	-14	11
58F107	37 13 48	76 33 35	80	57	50	22	5	22
58F123	37 14 24	76 32 45	71	64	57	23	7	23
59F1	37 15 35	76 37 35	50	44	22	-10	-38	-10
94297-1	37 11 52	76 32 45	50	35	--	23	-16	23
94298-1	37 11 34	76 32 15	39	31	23	23	-14	17
94306	37 10 57	76 30 27	55	–	46	12	–	12
94342	37 13 21	76 31 06	65	50	44	3	–	3
96198	37 14 08	76 30 22	7	–	–	-7	-17	-7

(Brockman and Richardson, 1992). The Columbia aquifer consists primarily of sandy sediments of Pleistocene age in the Windsor, Chuckatuck, Shirley, and Tabb Formations and unnamed sediments of Holocene age (fig. 5). Confined aquifers in these sediments are designated as part of the underlying Cornwallis Cave aquifer. Sediments of the Columbia aquifer are recorded in drillers' logs as fine-grained to coarse-grained sand, clay, silt, and shell. Horizontal hydraulic conductivity calculated from results of four slug tests at the Naval Weapons Station ranged from 0.4 to 8 feet per day (ft/d) (0.1 to 2.5m/d); vertical hydraulic conductivity calculated from results of permeameter tests on five cores collected at the Naval Weapons Station ranged from 1.7×10^{-4} to 1.7×10^{-1} ft/d (5.1×10^{-5} to 5.1×10^{-2} m/d) (Brockman and others, 1997).

Because the Columbia aquifer consists of sediments from different terrace deposits at different elevations, the permeable parts of these deposits do not form a single, laterally continuous, permeable zone throughout the battlefield (fig. 8 and table 2). This result is particularly evident where streams have incised the upland formations. Sediments that form the Columbia aquifer beneath the uplands crop out at the upper parts of valley walls or are covered by colluvium. Sediments that form the Columbia aquifer beneath the valleys also are present at much lower elevations (fig. 8 and table 2). The lateral extent of the Columbia aquifer beneath the valleys, however, is not known. Additionally, sediments of these formations are not saturated throughout much of the uplands. Because the permeable parts of the sediments are discontinuous and are not saturated in many areas, the Columbia aquifer is not a single continuous aquifer but is multiple discontinuous aquifers. Sediments that form the Columbia aquifer are likely saturated beneath the lowlands and beneath the center parts of the upland terraces away from the streams.

Cornwallis Cave confining unit

The Cornwallis Cave confining unit consists of silty and clayey sediments overlying the uppermost confined aquifer (Brockman and Richardson, 1992). It contains sediments of the lower Pliocene Moore House Member of the Yorktown Formation, the Sedley

Formation, and the Bacons Castle Formation; sediments of the Pleistocene Windsor, Chuckatuck, Shirley, and Tabb Formations; and (or) unnamed sediments of Holocene age (fig. 5). Sediments of the Cornwallis Cave confining unit are recorded in drillers' logs as clay, silt, and fine-grained sand with or without shell. Vertical hydraulic conductivity calculated from results of permeameter tests on five cores collected at the Naval Weapons Station ranged from 3.1×10^{-5} to 1.4×10^{-2} ft/d (9.4×10^{-6} to 4.3×10^{-3} m/d) (Brockman and others, 1997).

The hydraulic characteristics of the Cornwallis Cave confining unit vary laterally near Yorktown Battlefield because the formations in the confining unit and their permeability vary laterally. To the west of the Naval Weapons Station, the Cornwallis Cave confining unit contains sediments of the Sedley and Bacons Castle Formations beneath the Lackey Plain (Brockman and others, 1997). Vertical permeability of the confining unit in this area varies by a factor of about 500. The Sedley and Bacons Castle Formations, however, are absent beneath much of Yorktown Battlefield (C. Richard Berquist, Virginia Division of Mineral Resources, oral commun., 2000). Where the Sedley and Bacons Castle Formations are absent, the Cornwallis Cave confining unit can contain sediments of the weathered upper part of the Moore House member of the Yorktown Formation but more likely contains sediments of fine-grained parts of the Windsor, Chuckatuck, Shirley, and Tabb Formations and (or) fine-grained sediments of Holocene age. The particular formation in the Cornwallis Cave confining unit depends on the terrace that is present: the Windsor Formation beneath Grove Plain; the Chuckatuck Formation beneath Grafton Plain; the Shirley Formation beneath Huntington flat; the Tabb Formation along the York and James Rivers; and Holocene deposits in the stream valleys.

The Cornwallis Cave confining unit is not a single low-permeability unit throughout the battlefield. Because it consists of sediments from different terrace deposits that are at different elevations, the Cornwallis Cave confining unit is a series of discontinuous confining units that are not saturated throughout the battlefield (fig. 8). Additionally, these sediments do not appear to be of sufficiently low permeability to form a confining unit in all areas.

Although Brockman and Richardson (1992) did not delineate the Cornwallis Cave confining unit near Yorktown Battlefield, low permeability sediments that could form a confining unit are present at well 58F64. Such sediments that could form the Cornwallis Cave confining unit if the sediments were saturated are present at depths of 10 to 22 ft (3.0 to 6.5 m) (fig. 8, Section B-B'). These sediments are described as sand, gravel, and multi-colored clay. This interval shows elevated gamma radiation on the gamma log relative to adjacent parts of the log, which is typical of sediments that form the Cornwallis Cave confining unit near the battlefield. Because this well is located on the Grafton Plain, the confining unit likely contains sediments of the Chuckatuck Formation.

Sediments that form the Cornwallis Cave confining unit beneath the uplands have been eroded at many of the stream valleys and can be exposed at the upper parts of valley walls or covered by colluvium. This confining unit is likely present beneath at least parts of the stream valleys. Where the confining unit is present beneath the Beaverdam Creek valley, it likely will contain sediments of the Shirley Formation and (or) alluvial sediments (fig. 8, Section A-A') (C. Richard Berquist, Virginia Division of Mineral Resources, written commun., 2000). As with the Columbia aquifer, sediments of the Cornwallis Cave confining unit are more likely to be saturated beneath the lowlands and beneath the center parts of the upland terraces away from the streams.

Cornwallis Cave aquifer

The Cornwallis Cave aquifer consists primarily of sediments in the Moore House Member of the Yorktown Formation but also contains adjacent permeable parts of the overlying Pliocene Sedley and Bacons Castle Formations; Pleistocene Windsor, Chuckatuck, Shirley, and Tabb Formations; and (or) unnamed sediments of Holocene age (fig. 5). The sediments of these units are recorded in drillers' logs as shell, shell hash, coquina, silty (muddy) very fine-grained to coarse-grained sand, or biofragmented sand. The hydraulic properties of the Cornwallis Cave aquifer are highly variable because of depositional effects and because of physical and geochemical weathering. Iron deposits are common near the top of the unit where shell material buffers the acidic water flowing downward from overlying sediments. Highly permeable travertine (calcite) deposits locally underlie the iron at the mouth of numerous springs that feed the streams in the northern and northeastern parts of the battlefield. In other places, the dissolution of shell material and subsequent precipitation of calcite has cemented the shelly aquifer sediment; cementation can reduce the permeability of the sediments and the amount of contact area between ground water and the sediments. Horizontal hydraulic conductivity calculated from results of six slug tests at the Naval Weapons Station ranged from 0.3 to 9 ft/d (0.1 to 2.5 m/d); vertical hydraulic conductivity calculated from results of permeameter tests of 13 cores collected at the Naval Weapons Station ranged from $6.2x10^{-4}$ to $2.4x10^{-1}$ ft/d ($1.9x10^{-4}$ to $7.3x10^{-2}$m/d) (Brockman and others, 1997).

The Cornwallis Cave aquifer extends in the subsurface beneath most of Yorktown Battlefield and crops out in the valleys (fig. 8 and table 2). Its thickness varies greatly near the battlefield because of the presence of overlying terraces at different elevations and differences in the depth of incisement by the stream valleys. The Cornwallis Cave aquifer is fully incised by Ballard Creek and the York River in the northwestern part of the battlefield but is present beneath all uplands and all other stream valleys. At least the lower parts of the Cornwallis Cave aquifer are saturated throughout its extent.

Yorktown confining unit

The Yorktown confining unit primarily contains silt and clay of the Morgarts Beach Member of the Yorktown Formation (fig. 5). Sediments of the Yorktown confining unit are recorded in drillers' logs as clay, clayey silt, sandy clay, or silty clay with or without shell material. This unit is a distinctive dark greenish-gray. Vertical hydraulic conductivity calculated from results of permeameter tests of six cores collected at the Naval Weapons Station ranged from $1.3x10^{-5}$ to $7.4x10^{-3}$ ft/d ($4.0x10^{-6}$ to $2.3x10^{-3}$ m/d) (Brockman and others, 1997).

The Yorktown confining unit underlies the entire Yorktown Battlefield (figs. 8 and 9, and table 2). The top of the confining unit generally slopes to the east from about 25 ft (8 m) above sea level near the western boundary of the battlefield to probably more than 10 ft (3 m) below sea level at the eastern boundary (fig. 9). The top of the confining unit is at land surface only at the lower end of Ballard Creek and along the York River at the northwest boundary of the battlefield. Because of the depth and thickness of the Yorktown confining unit, stream valleys do not fully incise through the confining unit near the battlefield.

Yorktown-Eastover aquifer

The upper part of the Yorktown-Eastover aquifer primarily contains sediments of the Rushmere Member of the Yorktown Formation (fig. 5). These sediments are recorded in drillers' logs as fine-grained to medium-grained sand with small amounts of clay and minor amounts of shell. Horizontal hydraulic conductivity calculated from results of 15 slug tests at the Naval Weapons Station ranged from 0.004 to 0.4 ft/d (0.001 to 0.1 m/d); vertical hydraulic conductivity calculated from results of permeameter tests of 23 cores collected at the Naval Weapons Station ranged from $1.7x10^{-5}$ to $4.8x10^{-1}$ ft/d ($5.2x10^{-6}$ to $1.5x10^{-1}$ m/d) (Brockman and others, 1997).

The Yorktown-Eastover aquifer also underlies the entire Yorktown Battlefield (figs. 8 and 10). The top of the aquifer slopes to the east ranging from about sea level at the western boundary of the battlefield to more than 35 ft (11 m) below sea level at the eastern boundary. Because of the depth of the top of the Yorktown-Eastover aquifer, the aquifer is not exposed at land surface near the battlefield.

Conceptualized Ground-Water Flow

The shallow geology as reflected by the physiography near Yorktown Battlefield substantially affects ground-water flow through the shallow aquifer system. Because streams incise land surface and terrace deposits are present at different elevations, sediments that form the Columbia aquifer and Cornwallis Cave confining unit form discontinuous rather than laterally continuous geohydrologic units (figs. 8 and 11). The Cornwallis Cave aquifer is present throughout the area except at the northwest boundary of the battlefield along Ballard Creek and the York River. Its thickness varies because of differences in the depth of stream incisement, the elevation of the top of the Yorktown confining unit, and the elevation of the terraces. Incisement into the Cornwallis Cave aquifer creates a good hydraulic connection between the aquifer and the streams and wetlands. Because streams do not incise through the Yorktown confining unit and into the Yorktown-Eastover aquifer near the battlefield, the Yorktown-Eastover aquifer is not as well connected to

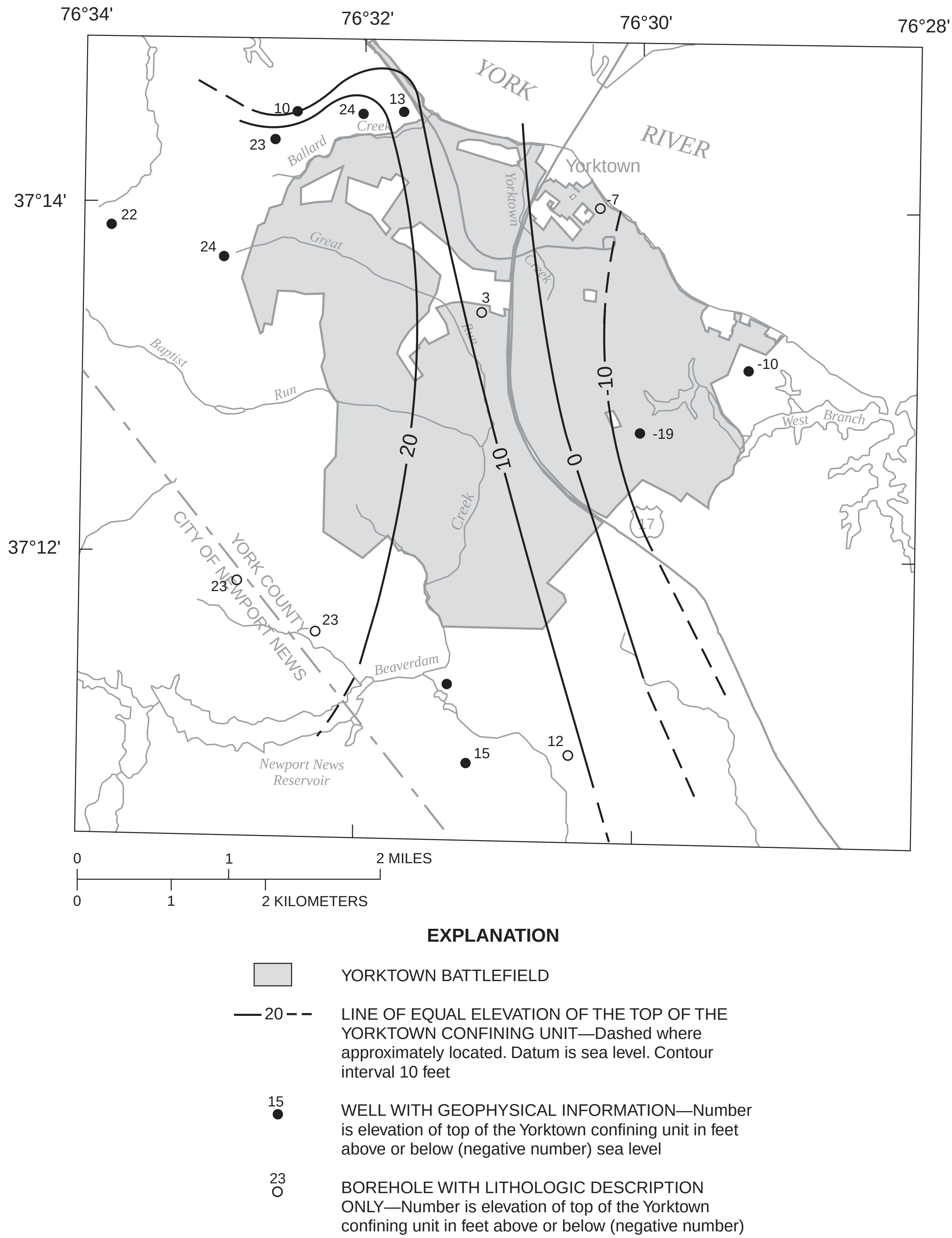
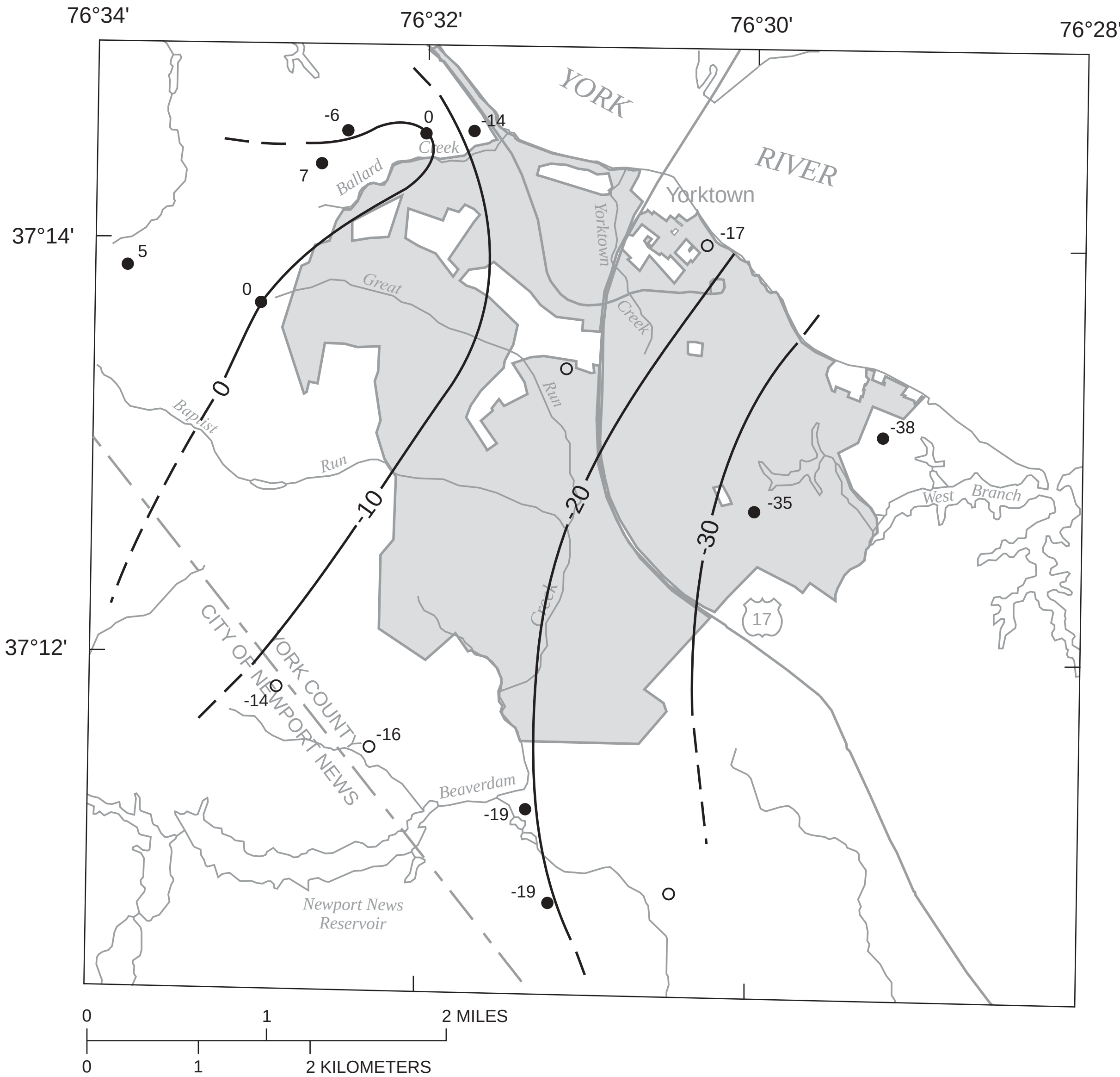


Figure 9. Altitude of top of Yorktown confining unit near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia.



EXPLANATION

YORKTOWN BATTLEFIELD

-20 LINE OF EQUAL ELEVATION OF THE TOP OF THE YORKTOWN-EASTOVER AQUIFER—Dashed where approximately located. Datum is sea level. Contour interval 10 feet

-19 WELL WITH GEOPHYSICAL INFORMATION—Number is elevation of top of the Yorktown-Eastover aquifer in feet above or below (negative number) sea level

-17 BOREHOLE WITH LITHOLOGIC DESCRIPTION ONLY—Number is elevation of top of the Yorktown-Eastover aquifer in feet above or below (negative number) sea level

Figure 10. Altitude of top of Yorktown-Eastover aquifer near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia.

streams and wetlands as the Cornwallis Cave aquifer. Thus, the Cornwallis Cave aquifer is the primary source of ground-water discharge to streams, wetlands, and associated habitats near Yorktown Battlefield; considerably less water flows through and discharges from the Yorktown-Eastover aquifer to streams, wetlands, and associated habitats. Because of the depth and continuity of the Yorktown confining unit, the Yorktown-Eastover aquifer is the most likely source of ground water originating outside the battlefield.

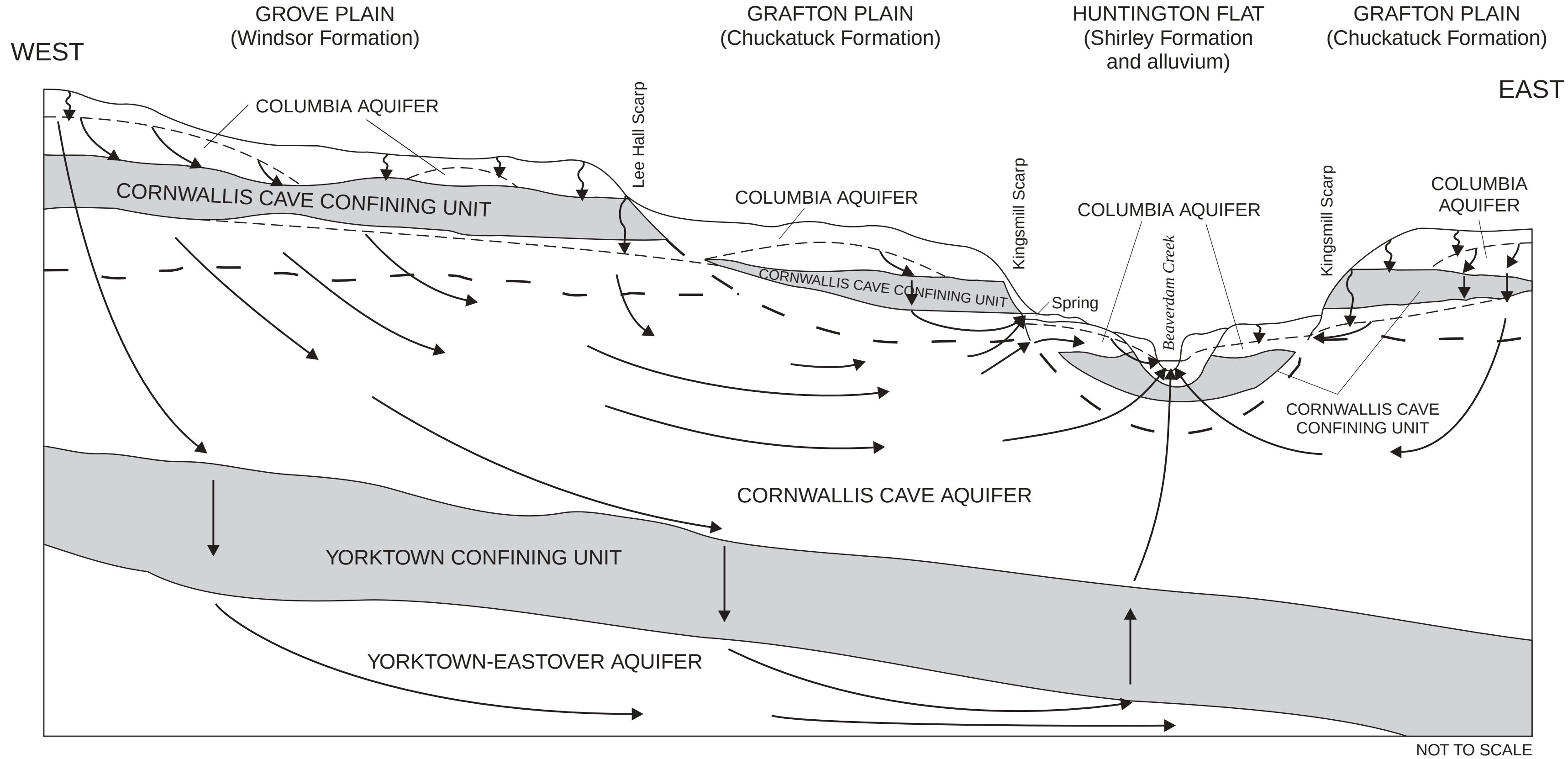
The lateral extent of saturated sediments also affects ground-water flow. The Columbia aquifer and Cornwallis Cave confining unit likely are saturated beneath the valleys because of the low elevation of the valleys. Sediments that typically form the Columbia aquifer and Cornwallis Cave confining unit, however, are not saturated beneath uplands of the entire battlefield. In many areas where these sediments are not saturated, the full thickness of sediments of the Cornwallis Cave aquifer is not likely saturated; consequently, the Cornwallis Cave aquifer is unconfined in these areas.

The Columbia aquifer and Cornwallis Cave confining unit likely are saturated beneath the uplands away from the streams. Brockman and others (1997) reported that sediments that commonly form the Columbia aquifer and Cornwallis Cave confining unit only are saturated beneath the uplands toward the center of inter-stream areas beneath Lackey Plain at the Naval Weapons Station. Similar conditions likely are present near the battlefield. Springs and seeps are present at the base of valley walls but not at the contact between low-permeability sediments and overlying high-permeability sediments at the upper parts of valley walls; this further demonstrates that sediments that commonly form the Columbia aquifer and Cornwallis Cave confining unit in the uplands are not saturated near stream valleys. Sediments that form the Columbia aquifer, the Cornwallis Cave confining unit, and the Cornwallis Cave aquifer are unsaturated beneath parts of the uplands because water readily drains where (1) the Cornwallis Cave confining unit is very leaky, (2) the permeability of the Cornwallis Cave aquifer is high, and (3) these sediments are incised by streams.

Ground water is recharged at the water table by precipitation that falls near Yorktown Battlefield. Recharge rates are likely the greatest during the late winter and early spring when rates of evapotranspiration are low. Recharge occurs where there is no standing water and where land surface is pervious and allows infiltration and percolation of precipitation. Ground water is also recharged beneath standing water where the hydraulic gradient between the standing water and the ground water is downward. Thus, ground water is recharged across most of the battlefield except where buildings and pavement create impervious surfaces and at streams, springs, and other standing waters where the hydraulic gradient is upward. In most lowland wetlands, the hydraulic gradient likely is upward during the growing season because ground water discharges through evapotranspiration. In such areas, however, the ground water can be recharged by precipitation when standing water is absent and the water table is below land surface because these conditions allow precipitation to infiltrate the soil and percolate to the water table. Rates of recharge vary because of spatial differences in precipitation amounts and rates, infiltration rates, percolation rates, land slope, and depth to the water table.

The shallow aquifer system is recharged by precipitation percolating to the water table of the shallowest aquifer, either the Columbia or Cornwallis Cave aquifer. Recharge is to the Columbia aquifer where sediments in the Columbia aquifer are saturated. Where sediments of the Columbia aquifer and Cornwallis Cave confining unit are unsaturated, the Cornwallis Cave aquifer is unconfined and is recharged directly by percolating water (fig. 11). The Columbia aquifer can be perched (saturated sediments underlain by unsaturated sediments) where the permeability of the Cornwallis Cave confining unit is sufficiently low and the Cornwallis Cave aquifer is unconfined. In these areas, the Cornwallis Cave aquifer is recharged by water that percolates from the Cornwallis Cave confining unit. Such perched conditions have not been identified and likely are temporary.

Ground water flows vertically and laterally from the water table through the shallow aquifer system toward areas of ground-water discharge (fig. 11). Water recharged near discharge areas likely flows along shallow, short flow paths; water recharged away from discharge areas likely flows along deep, long flow paths. Thus, water recharged near valleys flows along short flow paths and likely remains in the shallow aquifer system for short periods (possibly hours or days); water recharged beneath the uplands away from valleys flows along long flow paths and likely remains in the shallow aquifer system for longer periods



EXPLANATION

CONTACT BETWEEN THE MOORE HOUSE MEMBER OF THE YORKTOWN FORMATION AND THE OVERLYING TERRACE DEPOSIT

GROUND-WATER FLOW PATH

PERCOLATING RECHARGE

WATER TABLE

Figure 11. Generalized relation between geohydrologic units and ground-water flow paths near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia.

(possibly tens of years). Because of the extent of stream incisement into the Cornwallis Cave aquifer, water flowing through the aquifer does not likely flow past local streams. Water recharged near the center of the uplands, however, is the water most likely to flow downward and recharge and flow through the Yorktown-Eastover aquifer (fig. 11). Because streams near Yorktown Battlefield do not incise into the Yorktown-Eastover aquifer, the amount of water flowing through this aquifer probably is limited and is more likely to flow past local streams to more regional discharge areas than water flowing through the Cornwallis Cave aquifer. Thus, the Yorktown-Eastover aquifer is the most likely pathway for the flow of ground water to the battlefield from outside of the battlefield. The extent of flow through this aquifer past local streams requires further investigation. Water flowing through the Yorktown-Eastover aquifer that discharges to local streams and springs must flow upward through the overlying aquifers and confining units before it discharges.

Ground water discharges to ditches, seeps, springs, streams, and wetlands. Ditches are located in uplands and valleys. Seeps and springs generally are located near the base of valley walls, in flood plains, and in streambeds near the battlefield. Wetlands are primarily in stream valleys but are also present near upland sinkholes. Discharge to ditches, seeps, springs, and streams only occurs where the water table intercepts land surface. Discharge to wetlands also occurs where roots are of sufficient depth to withdraw water directly from the ground water or to cause water to flow from the water table through unsaturated sediments to the roots.

The large number of springs and seeps and the large volume of water that discharges from many of them make the springs and seeps important sources of discharge to surface waters near the battlefield. This discharge likely contains a mixture of water from different parts of the shallow aquifer system that converges at the spring. Thus, the quality of spring discharge probably better represents the average quality of water from nearby parts of the shallow aquifer system than that of water from wells. Water discharged from springs at the base of valley walls likely flows along shallower flow paths and is younger than water that discharges directly to streambeds or to springs in the streambeds.

Ground water discharges throughout the year although rates of discharge vary through time. Discharge to ditches, seeps, springs, and streams typically is greatest after recharge periods when ground-water levels are high; discharge rates decrease as ground-water levels decline. Ground-water discharge through evapotranspiration varies temporally in response to changes in the input of solar energy. Seasonally, evapotranspiration is least in the winter and greatest in the summer; during a 24-hour period, evapotranspiration typically is greatest in the afternoon and least at night.

GROUND-WATER QUALITY

The ground-water quality near Yorktown Battlefield differs between aquifers and varies spatially within an aquifer. These differences in water quality likely result from differences in (1) the quality of recharge water, (2) the age of the ground water, (3) the amount and type of shell material in aquifer sediments, (4) the amount and type of silicate minerals in aquifer sediments, and (5) spatial differences in the hydrology of the shallow aquifer system. Because of the small number of samples from springs that were analyzed, the magnitude and causes of differences in ground-water quality are inferred in many instances.

Columbia aquifer

Analyses of water from two springs indicate that water discharging from the Columbia aquifer has a low ionic strength, an acidic pH, and little buffering capacity (fig. 12). The quality of this spring water reflects the effects of the quality of recharge water, the young age of the water, the limited shell content of aquifer sediments, and the abundant silicate minerals in aquifer sediments.

Specific conductance (an indicator of ionic strength) of water from spring SP16 was 56 μS/cm and from spring SP39 was 130 μS/cm (table 3 and fig. 12). Although the chloride concentration in water from spring SP16 was 9.5 mg/L, chloride contributed 58 percent of the anions; sodium concentration was 5.3 mg/L and contributed 67 percent of the cations (table 3 and fig. 13). Chloride concentration in water from spring SP39 was 17 mg/L and contributed 50 percent of the anions. Although sodium concentration in water from this spring was 8.1 mg/L, sodium was only 41 percent of the cationic composition; no single ion was a majority of the cations. Observed concentrations of sodium and chloride can, in part, result from the effects of road salt, salt spray from the York River and James River estuaries and Chesapeake Bay, and other sources. The higher chloride and sodium concentrations in water from spring SP39 also could result from the effects of fertilizer application, septic-tank seepage, or other anthropogenic effects; this spring is adjacent to a residential area near the boundary of the battlefield.

The short flow paths and young age of the water and limited amount of shell material in sediments of the Columbia aquifer is reflected in the low calcium and bicarbonate concentrations and the low pH of the water (fig. 12). Calcium concentrations were 0.75 and 5.6 mg/L and bicarbonate concentrations were 0 and 6 mg/L in water from springs SP16 and SP39, respectively (table 3 and fig. 12). Because of the low bicarbonate concentrations, the water was poorly buffered; the pH of water from these springs was 4.5 and 5.1, respectively.

Silica and aluminum concentrations indicate the presence of silicate minerals in the sediments. Dissolved silica concentrations in water from these springs were near the silica saturation for quartz, 5.6 and 5.9 mg/L, respectively (table 3 and fig. 12). Water from the Columbia aquifer was the only sampled water having aluminum concentrations above the 15 μg/L MRL. Concentrations were 410 and 140 μg/L in water from springs SP16 and SP39, respectively. Although factors affecting aluminum solubility are complex, these concentrations likely resulted in part from the low pH of the water, which enhances silicate reactions and the solubility of aluminum (Drever, 1988).

Although concentrations of dissolved oxygen in water from these springs were 4.4 and 2.5 mg/L (table 3), iron concentrations were relatively elevated at 770 and 320 μg/L (fig. 12). Such iron concentrations usually are not observed in water having such high concentrations of dissolved oxygen. These high concentrations could result from a combination of (1) the presence of oxidized iron in colloidal forms, (2) the low pH of the water, and (3) the presence of dissolved iron in reduced form. The presence of iron deposits in the top of the shell-rich Cornwallis Cave aquifer indicates the effects of increasing pH on iron dissolved in water percolating from the overlying sediments that commonly form the Columbia aquifer. Because both samples from springs discharging from the Columbia aquifer were formed by seepage discharge, it is also possible that the water became aerated and that the dissolved-oxygen concentrations do not represent concentrations in the ground water.

Dissolved nitrogen concentrations generally were low in water discharging from the Columbia aquifer, indicating little effect from anthropogenic sources (table 3 and fig. 14). Dissolved organic plus ammonia nitrogen concentrations were 0.30 and 0.10 mg/L as nitrogen (N) from springs SP16 and SP39, respectively. Dissolved ammonia concentrations were only 0.003 and 0.012 mg/L as N, and dissolved nitrite concentrations were 0.001 and 0.005 mg/L as N, respectively. Nitrite-plus-nitrate concentrations were less than 0.005 mg/L as N and 0.579 mg/L as N in water from these two springs. The higher nitrite-plus-nitrate concentration in water from spring SP39 is accompanied by a slightly elevated chloride concentration (17 mg/L) and could result from the effects of fertilizer application, septic-tank seepage, or other effects of the nearby residential land use.

Similar to dissolved nitrogen concentrations, dissolved orthophosphorus and dissolved phosphorus concentrations in water from these springs were near their respective MRLs, 0.001 and 0.005 mg/L as phosphorus (P). Orthophosphorus concentrations were 0.002 and less than 0.001 mg/L as P and the dissolved phosphorus concentrations were 0.011 and 0.003 mg/L as P in water from springs SP16 and SP39, respectively (fig. 14).

Cornwallis Cave aquifer

Compared to water discharging from the Columbia aquifer, water discharging from the Cornwallis Cave aquifer has high concentrations of calcium and bicarbonate, a neutral to alkaline pH, and a large buffering capacity. The quality of water discharging from the Cornwallis Cave aquifer reflects the effects of (1) the quality of recharge water, (2) the age of the water, (3) spatial differences in the hydrology of the aquifer, (4) the presence of abundant shell material in aquifer sediment, and (5) the presence of silicate minerals in aquifer sediment. Spatial differences in water quality likely result from spatial differences in these factors, particularly differences in the hydrology and in the shell and silicate mineral content of the aquifer sediments. These differences appear to be related, in part, to whether the springs are in the York River Basin or the James River Basin. The hydrology of these areas likely differs because valleys

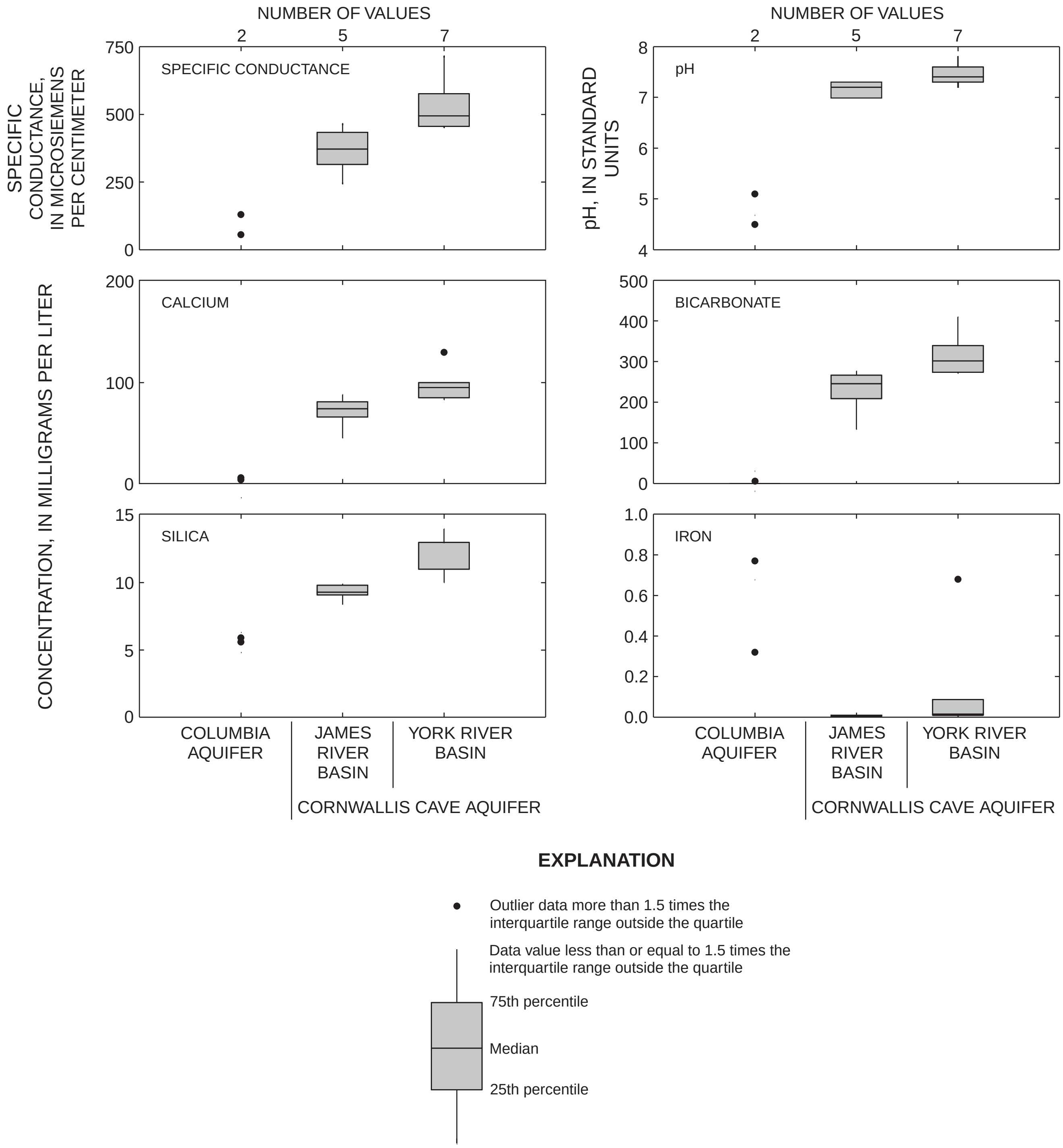


Figure 12. Specific conductance, pH, and concentrations of calcium, bicarbonate, silica, and iron in water from selected springs discharging from the Columbia aquifer and Cornwallis Cave aquifer near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia, April 2000.

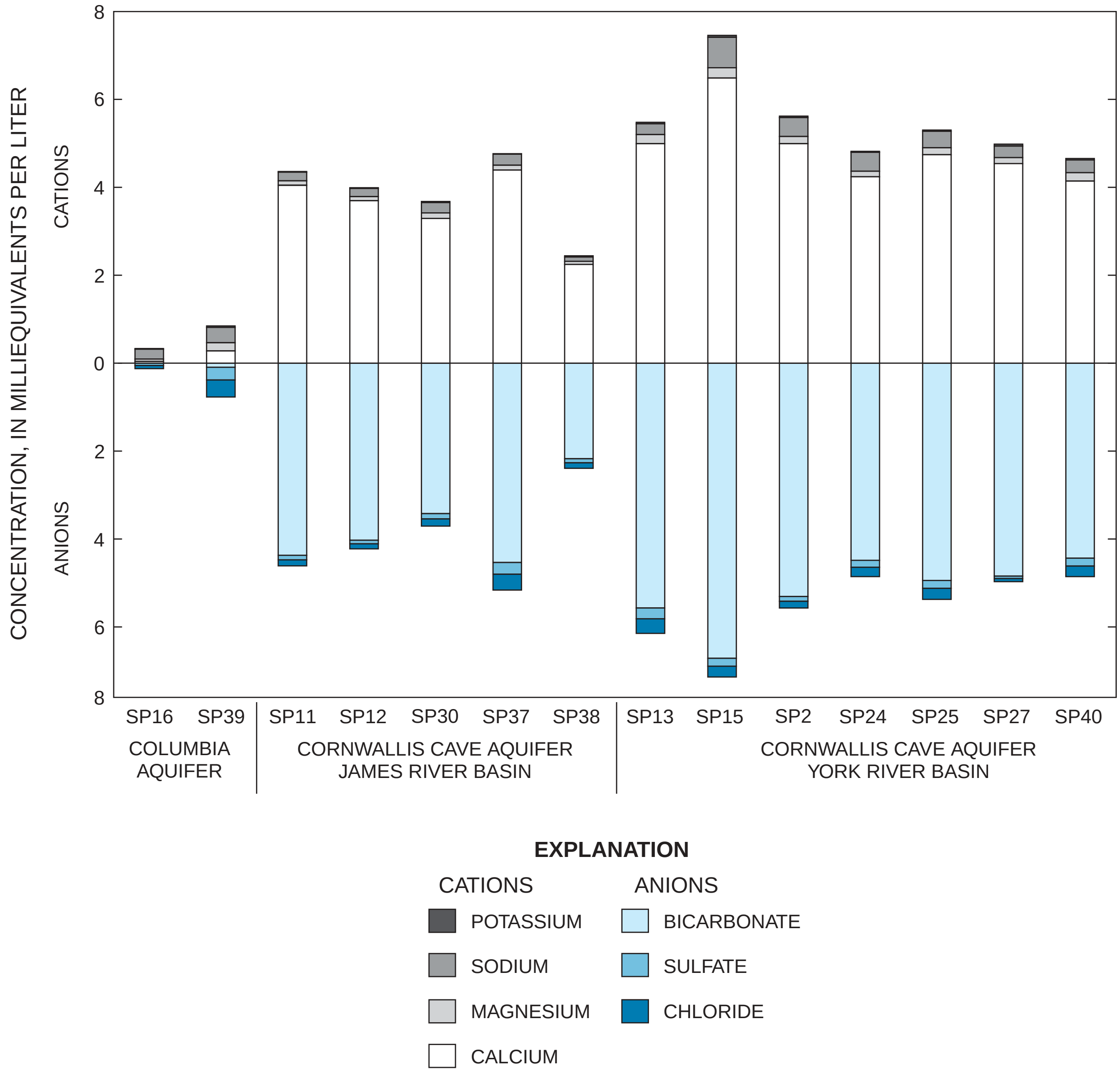


Figure 13. Concentration of major ions in water from selected springs near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia, April 2000. See figure 4 for locations of springs.

Table 3. Water-quality data from selected seeps and springs in April 2000 near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia

[mS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; –, no data]

Spring number	Local number	Station identification number	Date	Time	Specific conductance, (mS/cm)	Dissolved oxygen, (mg/L)	pH, units	Carbonate, dissolved (mg/L)	Bicarbonate, dissolved (mg/L)	Alkalinity, dissolved (mg/L as $CaCO_3$)	Chloride, dissolved (mg/L)
Springs Discharging from the Columbia Aquifer											
SP16	58FS 29	371344076323801	4/11/00	1630	56	4.4	4.5	0	0	0	9.5
SP39	58FS 50	371208076301501	4/11/00	1045	130	2.5	5.1	0	6	4	17
Springs Discharging from the Cornwallis Cave Aquifer to the James River Basin											
SP12	58FS 14	371211076315301	4/11/00	1430	315	2.5	7.2	0	246	202	6.3
SP11	58FS 25	371213076320401	4/11/00	1410	434	2.5	7.3	0	267	219	5.8
SP37	58FS 27	371223076311501	4/11/00	1300	467	.8	7.0	0	277	227	9.1
SP38	58FS 28	371242076312101	4/11/00	1545	243	6.8	7.2	0	133	109	4.8
SP30	58FS 43	371321076312601	4/11/00	1700	372	3.5	7.2	0	209	171	7.3
Springs Discharging from the Cornwallis Cave Aquifer to the York River Basin											
SP 2	58FS 17	371330076305501	4/11/00	1900	577	5.0	7.2	0	324	266	21
SP13	58FS 26	371305076300801	4/12/00	845	536	2.4	7.3[a]	0	340	279	8.7
SP24	58FS 37	371403076313401	4/12/00	1215	458	7.6	7.4[a]	0	274	225	15
SP25	58FS 38	371402076313901	4/12/00	1245	495	7.8	7.8	0	302	248	14
SP27	58FS 40	371355076311001	4/12/00	1045	451	7.6	7.3[a]	0	296	243	11
SP40	58FS 51	371331076303801	4/11/00	1830	456	4.7	7.4	0	271	222	10
SP15	59FS 2	371315076293601	4/12/00	930	717	3.7	7.4	0	410	336	37

[a] Reported value was measured in the laboratory rather than in the field.

Table 3. Water-quality data from selected seeps and springs in April 2000 near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia—Continued

[mg/L, milligrams per liter; N, nitrogen; P, phosphorus; --, no data; <, less than: E, estimated value less than the minimum reporting limit]

Spring number	Date	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Calcium, dissolved (mg/L)	Magne-sium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Silica, dissolved (mg/L)	Iron, dissolved (mg/L)	Manganese, dissolved (mg/L)	Aluminum, dissolved (mg/L)
Springs Discharging from the Columbia Aquifer												
SP16	4/11/00	2.8	<0.10	<0.010	0.75	0.72	5.3	0.71	5.6	770	5.0	410
SP39	4/11/00	14	<.10	.061	5.6	2.3	8.1	1.6	5.9	320	85	140
Springs Discharging from the Cornwallis Cave Aquifer to the James River Basin												
SP12	4/11/00	4.0	<.10	.039	74	1.2	4.5	.63	9.1	<10	<2.2	<15
SP11	4/11/00	5.1	<.10	.040	81	1.3	4.6	.71	9.8	E6.8	<2.2	E12
SP37	4/11/00	13	<.10	.038	88	1.4	5.9	.42	9.3	E7.4	<2.2	<15
SP38	4/11/00	4.7	.10	.028	45	.94	2.4	.77	8.4	E5.1	<2.2	E12
SP30	4/11/00	6.0	<.10	.047	66	1.6	5.4	1.1	9.9	E9.1	<2.2	E13
Springs Discharging from the Cornwallis Cave Aquifer to the York River Basin												
SP 2	4/11/00	5.6	<.10	.10	100	2.1	10	1.3	13	65	21	<15
SP13	4/12/00	12	<.10	.051	100	2.6	5.8	1.2	11	18	E2.0	<15
SP24	4/12/00	7.7	<.10	.057	85	1.6	10	.85	14	15	3.5	<15
SP25	4/12/00	8.9	<.10	.060	95	2.0	8.8	.98	13	<10	<2.2	<15
SP27	4/12/00	2.7	<.10	.055	91	1.7	6.2	1.6	12	E8.5	8.9	<15
SP40	4/11/00	8.8	<.10	.044	83	2.4	6.7	1.3	10	87	22	<15
SP15	4/12/00	8.9	<.10	.061	130	2.9	16	1.7	13	680	207	E10

Table 3. Water-quality data from selected seeps and springs in April 2000 near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia–Continued

[mg/L, milligrams per liter; N, nitrogen; P, phosphorus; –, no data; <, less than: E, estimated value less than the minimum reporting limit]

Spring number	Date	Solids, residue at 180°C, dissolved, (mg/L)	Solids, sum of constituents, dissolved, (mg/L)	Nitrogen organic plus ammonia, (mg/L as N)	Nitrogen ammonia, (mg/L as N)	Nitrogen nitrite plus nitrate, (mg/L as N)	Nitrogen nitrite, (mg/L as N)	Phosphorus dissolved, (mg/L as P)	Phosphorus ortho, dissolved, (mg/L as P)
Springs Discharging from the Columbia Aquifer									
SP16	4/11/00	53	–	0.30	0.003	<0.005	0.001	0.011	0.002
SP39	4/11/00	69	60	E.10	.012	.579	.005	E.003	<.001
Springs Discharging from the Cornwallis Cave Aquifer to the James River Basin									
SP12	4/11/00	224	221	<.10	.012	.033	<.001	.046	.044
SP11	4/11/00	253	240	<.10	.015	.040	<.001	.052	.048
SP37	4/11/00	273	263	<.10	.016	.055	<.001	.032	.030
SP38	4/11/00	147	139	E.10	.002	1.27	<.001	.052	.050
SP30	4/11/00	213	201	<.10	.006	.286	<.001	.029	.027
Springs Discharging from the Cornwallis Cave Aquifer to the York River Basin									
SP 2	4/11/00	330	317	E.10	.031	.697	.001	.040	.036
SP13	4/12/00	332	313	<.10	.024	.224	<.001	E.005	.004
SP24	4/12/00	276	270	<.10	.017	.051	<.001	.021	.018
SP25	4/12/00	309	291	<.10	.021	.051	<.001	.040	.040
SP27	4/12/00	286	271	<.10	.016	.026	<.001	.064	.060
SP40	4/11/00	265	258	E.10	.036	.430	.001	.010	.008
SP15	4/12/00	447	414	.16	.095	.009	.001	.006	<.001

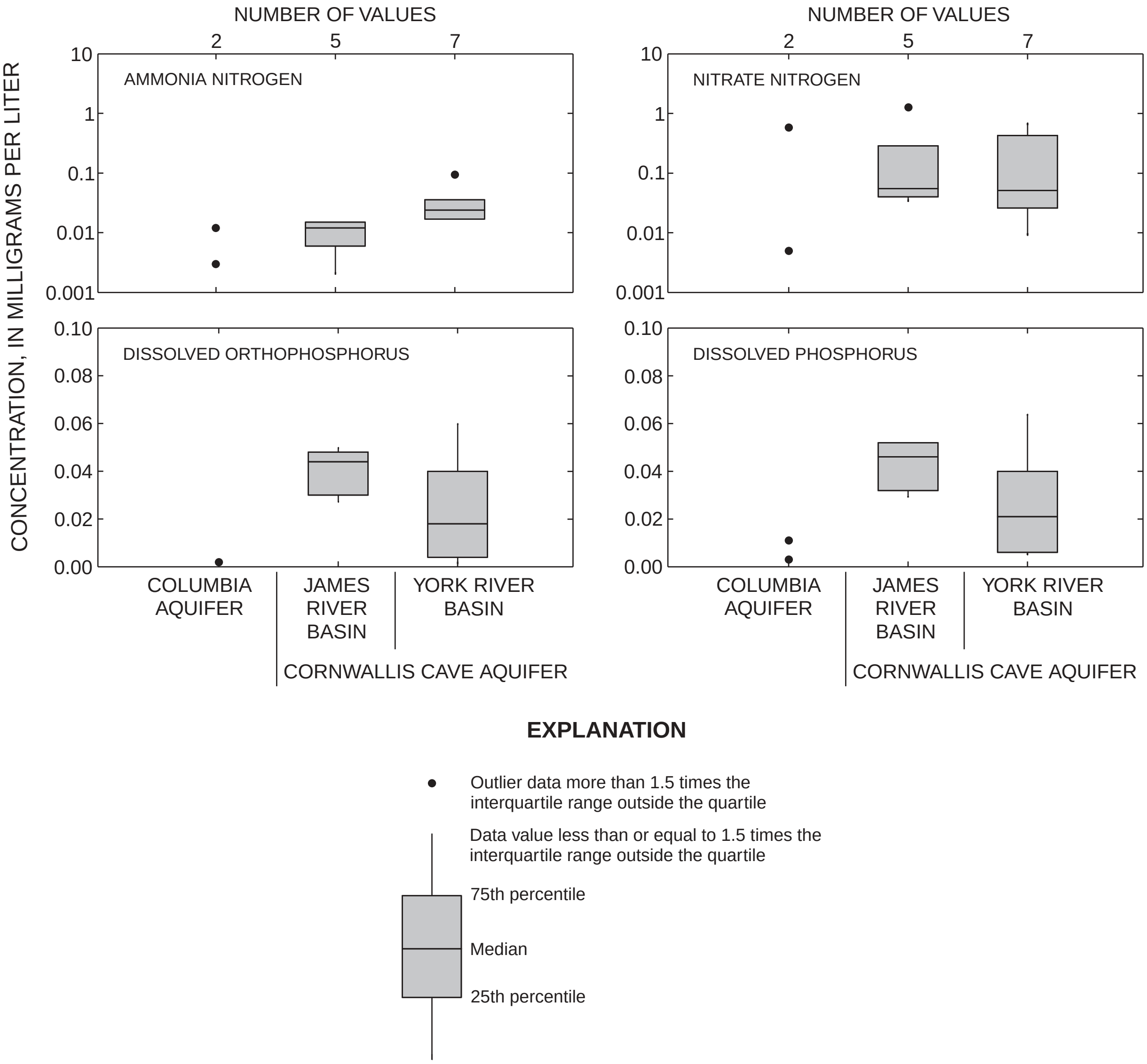


Figure 14. Concentrations of nutrients in water from selected springs discharging from the Columbia aquifer and Cornwallis Cave aquifer near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia, April 2000.

in the York River Basin are shorter, are more deeply incised, and have steeper walls than valleys in the James River Basin and because the upland terraces between the streams are narrower in the York River Basin. These differences likely result in shorter flow paths and more rapid ground-water flow in the York River Basin than in the James River Basin.

Spatial differences in the shell and silicate mineral content of aquifer sediments can result from spatial differences in the deposition and (or) subsequent weathering of these materials. Although spatial differences in the lithology and shell content of the Cornwallis Cave aquifer have been observed in outcrop and core samples, the spatial distribution of these differences has not been delineated. Because the effects of spatial differences in the hydrology and the silicate mineral and shell content appear to be related to the basin to which the spring drains, much of the following discussion identifies differences in water quality between these basins.

Water discharging from the Cornwallis Cave aquifer had a higher ionic strength and a different ionic composition than water discharging from the Columbia aquifer (figs. 12 and 13), probably because of the greater abundance of shell material and the greater age of water in the Cornwallis Cave aquifer. Specific conductance of water discharging from the Cornwallis Cave aquifer ranged from 243 to 717 µS/cm (fig. 12). The specific conductance of water discharging to the York River Basin generally was higher than that of water discharging to the James River Basin (fig. 12).

The ionic composition of water discharging from the Cornwallis Cave aquifer was relatively consistent across the battlefield. Bicarbonate ion was the major anion, contributing 88 to 97 percent of the anions; calcium was the major cation, contributing 87 to 93 percent of the cations (fig. 13). The high concentrations of bicarbonate and calcium resulted from the dissolution of shell material contained in the aquifer. Although bicarbonate was consistently the dominant anion in spring water, concentrations varied substantially, ranging from 133 to 410 mg/L (figs. 12 and 13). Calcium concentrations also varied substantially, ranging from 45 to 130 mg/L.

Like specific conductance, concentrations of bicarbonate and calcium ions differed with the basin to which the springs discharged. Concentrations of both bicarbonate and calcium generally were greater in water discharging to the York River Basin than in water discharging to the James River Basin (fig. 12). These differences could result from various factors. The amount of aragonite shell material could be greater near the York River Basin than near the James River Basin, providing more material for dissolution. Spatial differences in the amount of aragonite could result from spatial differences in the deposition or weathering of the aragonite material. Another possible cause for differences in bicarbonate and calcium concentrations is that water flows more rapidly through the aquifer in the York River Basin than in the James River Basin because of the greater stream incisement and narrower uplands in the York River Basin. Although rapid flow and young water typically are associated with relatively low concentrations of dissolved constituents, rapid flow can limit the precipitation of calcite, resulting in higher concentrations of calcium and bicarbonate, as indicated by Drever (1988). Travertine (calcite) deposits are more common in the beds of streams draining to the York River Basin than in streams draining to the James River Basin; the more turbulent flow in the streams than in the aquifer can facilitate precipitation of calcite in the streams.

Concentrations of dissolved silica also differed with the basin to which the springs discharge. Concentrations of dissolved silica were higher in water discharging to the York River Basin (10 to 14 mg/L) than to the James River Basin (8.4 to 9.9 mg/L) (fig. 12). A possible reason for this difference is that greater amounts of calcite precipitate and coat silicate mineral surfaces in the shallow aquifer system underlying the James River Basin where the water flows slowly, thereby reducing the amount of surface area for reactions between the minerals and water.

Water discharging from the Cornwallis Cave aquifer is well buffered because of the high concentrations of bicarbonate ion. Consequently, the pH of water discharging from the Cornwallis Cave aquifer was higher than that of water discharging from the Columbia aquifer, ranging from 7.0 to 7.8 (table 3 and fig. 12). Similar to concentrations of bicarbonate, calcium, and silica, pH generally was higher in water from springs discharging to the York River Basin than to the James River Basin. This result is consistent with the higher alkalinity in the York River Basin than in the James River Basin.

Concentrations of dissolved oxygen were highly variable, ranging from 0.8 to 7.8 mg/L. (table 3). Such concentrations generally are sufficient for the oxidation of iron and manganese and for the nitrification of ammonia to nitrate. Measured concentrations, however, do not necessarily represent concentrations in the ground water. Where water is derived from diffuse seepage, concentrations can increase when the water is aerated as it collects in shallow sinuous channels. Where these channels contain abundant organic material, concentrations of dissolved oxygen can decrease as the water flows through decomposing organic material. Where flow is through a focused spring discharge, the water can flow through cavities beneath land surface and become aerated before the water discharges.

Similar to concentrations of bicarbonate, calcium, and silica, concentrations of iron and manganese differed between springs discharging to the York River Basin and the James River Basin. Concentrations of iron and manganese in water discharging to the James River Basin were all less than the respective MRLs (10 and 2.2 µg/L) (table 3 and fig. 12). Concentrations of iron and manganese in water discharging to the York River Basin were variable, ranging from less than the MRLs to 680 and 207 µg/L, respectively.

Concentrations of aluminum were less than the 15 µg/L MRL in all water discharging from the Cornwallis Cave aquifer. Aluminum concentrations likely were low because solubility of aluminum is low when the pH is higher than 7.0 (Drever, 1988).

Concentrations of all dissolved nitrogen species except nitrite plus nitrate were relatively low in all spring water (table 3 and fig. 14). Concentrations of dissolved organic plus ammonia nitrogen generally were less than 0.10 mg/L as N. Concentrations of dissolved ammonia were less than 0.1 mg/L as N and were slightly higher in springs in the York River Basin than in the James River Basin (fig. 14). Concentrations of nitrite were near the MRL of 0.001 mg/L as N. Dissolved nitrite-plus-nitrate concentrations were the highest and most variable of the nitrogen species, ranging from 0.009 to 1.27 mg/L as N (table 3 and figs. 14 and 15). Nitrite-plus-nitrate concentrations varied spatially but did not appear to relate to the basin to which the springs drain. Concentrations in water from five springs near the center of the battlefield were higher than 0.200 mg/L as N, whereas concentrations in water from the seven springs toward the outer boundaries were 0.055 mg/L as N or less. The higher nitrate concentrations near the center of the battlefield could result from natural sources, historical activities at the battlefield, or present-day anthropogenic sources. No present-day anthropogenic sources of nitrogen are known in areas around springs having elevated nitrate concentrations.

(Figure 15 near here.)

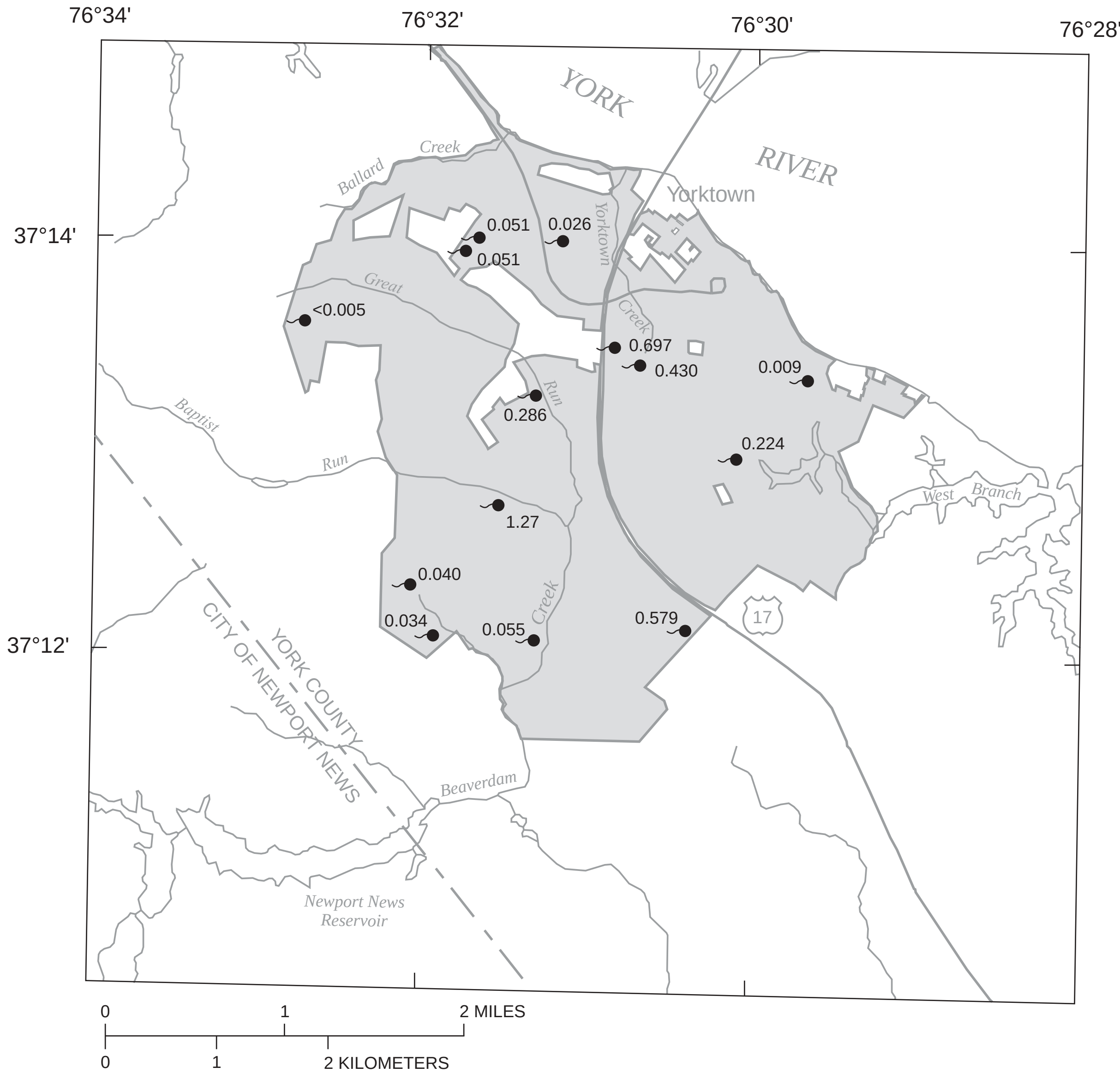
Dissolved phosphorus concentrations also were low and consisted primarily of dissolved orthophosphorus (table 3 and fig. 14). Concentrations of dissolved phosphorus ranged from 0.005 to 0.064 mg/L as P; concentrations of orthophosphorus ranged from less than 0.001 mg/L as P to 0.060 mg/L as P. The part of dissolved phosphorus not consisting of orthophosphorus (the difference between dissolved phosphorus and orthophosphorus) was 0.006 mg/L as P or less in all samples. Concentrations of dissolved phosphorus and orthophosphorus were somewhat higher in the James River Basin than in the York River Basin.

DISCUSSION

Streams, wetlands, and associated habitats near Yorktown Battlefield are nursery grounds for juvenile fish, nesting areas for birds, and habitats for rare, threatened, and endangered species. Colonial National Historical Park has the second-largest number of threatened and endangered species among National Park System units in Virginia (Virginia Department of Conservation and Recreation, 1993). Because Colonial National Historical Park is located in one of Virginia's most rapidly expanding population centers, the Hampton Roads metropolitan area, the preservation of critical aquatic habitat is of growing concern.

Ground-water discharge is an important source of water to the streams, wetlands, and aquatic habitats near Yorktown Battlefield. Discharge pathways include (1) seeps and springs, (2) ditch bottoms and streambeds, and (3) evapotranspiration from saturated and unsaturated sediments. Ground-water discharge is primarily from the Cornwallis Cave aquifer; small amounts of water also discharge from the Columbia and Yorktown-Eastover aquifer. Consequently, the quantity and quality of water discharging from the Cornwallis Cave aquifer can substantially affect the streams and wetlands near Yorktown Battlefield. Habitats in upland areas such as sinkhole wetlands can be affected by water discharging from the Columbia aquifer.

Because stream incisement into the Cornwallis Cave aquifer limits the distance that ground water



EXPLANATION

YORKTOWN BATTLEFIELD

1.27 SPRING AND CONCENTRATION OF NITRITE PLUS NITRATE, IN MILLIGRAMS PER LITER AS NITROGEN

Figure 15. Concentrations of nitrite plus nitrate in water from selected springs near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia, April 2000.

flows, most water discharging near Yorktown Battlefield probably was recharged through adjacent uplands, which are generally within the outer boundary of the battlefield and in nearby areas surrounding the battlefield. Thus, the quality of ground water that discharges to the battlefield is most affected by land use and cover (1) within the battlefield, (2) in those areas interspersed inside the outer boundary of the battlefield that are not battlefield property, and (3) in nearby areas surrounding the battlefield. Because Ballard Creek fully incises the Cornwallis Cave aquifer at the lower part of the creek and through a large part of the aquifer in the upper part of the creek, ground-water flow under Ballard Creek to other streams and wetlands is likely limited. The greatest potential for flow under Ballard Creek and other streams throughout the battlefield is through the Yorktown-Eastover aquifer. Because water that flows through the Yorktown-Eastover aquifer must flow downward and back up through the Yorktown confining unit before discharging to the surface, probably only small amounts discharge from this aquifer to most streams near the battlefield. Thus, stream incisement and the low permeability of the Yorktown confining unit probably limit the potential for contamination of ground water from sources outside of the outer battlefield boundary.

The quality of water discharging from the Cornwallis Cave aquifer is substantially affected by the dissolution of shell material, which contributes high concentrations of bicarbonate and calcium ions to the water. The bicarbonate buffers the water from the effects of acid from atmospheric deposition and other sources. Water discharging from the Columbia aquifer, however, is poorly buffered. The pH of water discharging from springs from the Cornwallis Cave aquifer ranged from 7.0 to 7.8 in contrast to the 4.5 and 5.1 of water from the two springs discharging from the Columbia aquifer. Thus, wetland habitats that are hydraulically connected to the Columbia aquifer might be more susceptible to acidification than those hydraulically connected to the Cornwallis Cave aquifer. This buffering also appears to limit concentrations of aluminum in ground-water discharge; aluminum concentrations were less than the 15 μg/L MRL in water discharging from the Cornwallis Cave aquifer, whereas concentrations were as high as 410 μg/L in water from springs discharging from the Columbia aquifer. Concentrations of aluminum in ground-water discharge are important because aluminum can be toxic to certain biota.

Concentrations of dissolved constituents are different in water from springs discharging to the York River Basin compared to the James River Basin. These differences can result from the effects of (1) stream incisement, (2) the length of ground-water flow paths, (3) the shell content of aquifer sediments, (4) ground-water age, and (5) the mixing of water of different ages and chemistry. The relative importance of these factors, however, is not known. Older water can result in dissolution of more shell (increasing concentrations of calcium and bicarbonate) on the one hand and the precipitation of more calcite (decreasing concentrations of calcium and bicarbonate) on the other. Because calcium and bicarbonate concentrations are higher in water discharging from the Cornwallis Cave aquifer in the York River Basin, it is likely that either more shell material is available for dissolution or less calcite precipitates from solution in the aquifer beneath the York River Basin than beneath the James River Basin.

The analysis of the shallow aquifer system near Yorktown Battlefield contained in this report is based primarily on surface information (soils, outcrops, topography, and springs) at the battlefield and on subsurface information from wells and boreholes surrounding the battlefield. The resulting conceptualized framework and flow provide only a basic understanding of the shallow aquifer system and how it affects the quality and quantity of water in streams, wetlands, and associated habitats near the battlefield. Because of the complex geology and the lack of appropriate wells and other subsurface information at the battlefield, additional research is needed on the factors affecting the flow and quality of water in the shallow aquifer system and on the effects of the shallow ground water on these surficial systems at the battlefield. Results of this research will help in protecting and managing the streams, wetlands, and associated habitats at Yorktown Battlefield.

FUTURE MONITORING AND RESEARCH

Because ground-water and surface-water systems connect Yorktown Battlefield with surrounding areas, future monitoring and research at the battlefield could include the surrounding areas. Monitoring and research of the effects of the shallow aquifer system on the quantity and quality of water discharged to streams, wetlands, and associated habitats near Yorktown Battlefield would include (1) monitoring the quantity and quality of water from different parts of the hydrologic system, (2) continued development of the geohydrologic framework, and (3) evaluations of the connection between the shallow aquifer system and the streams, wetlands, and associated habitats. Monitoring and research should be conducted concurrently.

Monitoring

Monitoring the quantity and quality of water in different parts of the hydrologic system provides essential information for refining the framework and for evaluating the flow of water and transport of contaminants through the shallow aquifer system to streams, wetlands, and associated habitats. A well-designed monitoring program can collect the essential data at minimal cost, and results can help to refine long-term environmental monitoring programs. Monitoring design will include selection of monitoring sites, properties to be measured, and the frequency and timing of measurements. As an example, monthly or quarterly monitoring of ground-water quality is often considered essential to determine seasonal patterns in ground-water quality and the cause-and-effect relations. Such a monitoring frequency can be of limited value in parts of the system where the age of the ground water is more than 10 years. Frequent monitoring of young water, however, can be essential for identifying short-term changes in water quality. For surface-water systems, knowledge of the temporal distribution of surface runoff and ground-water discharge can be used to determine the timing of sample collection that targets a particular problem of concern. The following components would be part of the monitoring program:

- Inventory and record key information on additional springs and seeps near the battlefield (springs and seeps in addition to those identified by Focazio (1997) during dry conditions are present during wet conditions).
- Measure the amount of precipitation and collect other meteorological information from at least one site near the battlefield. Collect and analyze the quality of precipitation samples.
- Measure water levels continuously in selected piezometers and periodically in others.
- Measure streamflow continuously at selected sites.
- Measure streamflow and spring discharge throughout the battlefield during selected high and low base-flow periods.
- Periodically collect and analyze water samples from piezometers, springs, streambed seepage collectors, and mini-piezometers located in sections across streambeds. Collect and analyze stream-water samples at continuous streamflow-gaging stations and at other sites in conjunction with measuring discharge.
- Collect and analyze water samples from springs at intervals of less than an hour to days, depending on flow variability, to determine if the quality changes as flow increases then decreases as a result of recharge and discharge.
- Analyze water samples from precipitation, wells, springs, and streams for properties to establish naturally occurring background levels and hydrologic and geochemical processes. Such properties include field-measured properties and concentrations of major ions, heavy metals, silica, nutrients, organic carbon, the stable isotopes of oxygen and hydrogen, and nitrogen isotopes. Determine the age of selected ground-water samples.
- Analyze selected samples for properties possibly affected by anthropogenic factors such as concentrations of volatile organic compounds, heavy metals, and other organic compounds of concern.

Geohydrologic Framework

The geohydrologic framework of the shallow aquifer system near Yorktown Battlefield needs continued development. The framework provides the conceptualization of the physical constraints that control ground-water flow, contaminant transport, and discharge of water and contaminants. A more detailed framework is necessary to evaluate many of the hydrologic issues of concern at the battlefield.

Information on the framework within the boundaries of Yorktown Battlefield is extremely limited. The formations that make up the Columbia aquifer and the Cornwallis Cave confining unit at specific locations are uncertain because of the presence of different terrace deposits near land surface. Knowledge of the spatial variability in the thickness and hydraulic characteristics of these units is also important. Knowing the location of saturated and unsaturated sediments in these formations is also essential in evaluating ground-water flow, contaminant transport, and the interaction between the shallow aquifer system and the streams, wetlands, and associated habitats.

Further development of the framework will require an extensive effort with particular emphasis around areas of the greatest likely variability in the shallow aquifer system such as near scarps and stream valleys. ***The following components are essential for further development of the framework:***

- Obtain new geologic data from other sources and evaluate rock outcrops near the battlefield.
- Install piezometers in clusters with piezometers installed at the top, bottom, and midpoints of each aquifer as appropriate. Install individual piezometers at the water table at selected locations. Piezometers should be located in upland recharge areas and in areas near springs, wetlands, stream banks, and streambeds.
- Obtain sediment cores from boreholes at the sites of piezometer installations and other locations.
- Obtain new borehole geophysical logs of existing and newly installed wells and piezometers and of boreholes of sufficient depth for which geophysical logs are not available or for which existing logs are inadequate.
- Describe the lithology of sediment cores.
- Determine the vertical hydraulic conductivity of selected sediment cores.
- Determine the horizontal hydraulic conductivity and specific yield of the aquifer sediments.
- Conduct a detailed mineral analysis of selected aquifer and confining unit sediments.
- Conduct surface geophysical surveys of areas having local geohydrologic anomalies or for which greater local detail is desired. These local areas would include scarps, other areas of likely changes in geology, and areas around springs.
- Construct geohydrologic sections and maps that depict the lateral extent, elevation, and thickness of the aquifers and confining units.
- Coordinate efforts with C. Richard Berquist of the Virginia Division of Mineral Resources, Gerald H. Johnson of the College of William and Mary, and Scott Emry of the Hampton Roads Planning District Commission.

Connection between the Shallow Aquifer System and Streams, Wetlands, and Associated Habitats.

Evaluation of the connection between the shallow aquifer system and the streams, wetlands, and associated habitats will provide knowledge of the cause-and-effect relations that affect the quantity and quality of ground water that discharges to these areas. This knowledge is essential in protecting and maintaining critical aquatic habitats. The following identifies selected possible research and its benefits.

- Rates of ground-water discharge to wetlands: The relative importance of ground-water discharge to wetlands changes seasonally and annually. When precipitation and surface runoff are plentiful, the importance of ground-water discharge is limited; during dry periods, ground-water discharge is the only source of water to certain habitats. Thus, ground-water discharge can be essential to the preservation of certain wetland habitats.
- The hydrologic connection between sinkhole ponds and the shallow aquifer system: The hydrologic connection between sinkhole ponds and the shallow aquifer system from the water table to saturated sediments in the Cornwallis Cave aquifer and the location of the ponds in the physiographic setting can affect the timing and duration of standing water. Because sinkholes likely are directly connected to the Columbia aquifer, these systems likely are poorly buffered and susceptible to contamination from outside sources. By better understanding the role of these connections in maintaining wet conditions and the water quality, appropriate preservation techniques can be identified.
- Ground-water flow paths and age: Determination of ground-water flow paths and age is among the most essential needs for evaluating the effects of ground-water discharge to streams and wetlands. This research is essential in evaluating sources of contaminants and their transport through the system. This research also is critical for designing effective monitoring and other research at Yorktown Battlefield.

- Percolation of water and transport of contaminants from land surface to the water table: Where the water table is deep (more than 10 ft), water and contaminants can take years to reach the water table. This time and associated geochemical processes can substantially affect the contribution of contaminants to, and flushing of contaminants from, the shallow aquifer system.

Two project statements were developed to address some of these research needs and are included in Appendix A. These statements were developed for this report according to NPS standards at the time the project was started. During the project, the NPS changed procedures and implemented the Project Management and Information System (PMIS) that includes a repository for project statements. The first project statement in the appendix was modified and is in the PMIS.

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PROJECT STATEMENT 1

Title: Effects of Hydrology on the Hydroperiods and Water Quality of Sinkhole Ponds, Yorktown Battlefield, Virginia

Park: Colonial National Historical Park - Yorktown Battlefield

Service-Wide Issues:

Amount Requested: $305,000 over three years

Park Contact: Charles Rafkind

ABSTRACT

Sinkholes formed by the collapse of surface sediment after the dissolution of underlying shell material are scattered across the uplands at Yorktown Battlefield, Colonial National Historical Park, Virginia, and surrounding areas. These sinkholes fill with water from the winter to early summer, forming seasonal ponds that are important habitat for amphibians and other organisms. The sources of water to the sinkholes and flow paths to and from the sinkholes affect both the hydroperiods (seasonal pattern of water levels) and the water quality of these ponds and their suitability as habitat for these organisms. The purpose of this project is to evaluate the effects of these sources on the hydroperiods and the water quality of selected sinkhole ponds and the likely effects of the water quality on the ponds as habitat. This information will be used by park staff to manage and protect sinkhole ponds and associated ecosystems that have had minimal disturbance and to restore those that have been appreciably altered.

PROBLEM

Yorktown Battlefield, Colonial National Historical Park, is located in York County, Virginia, between the James River and York River estuaries (fig. A1). The battlefield is in the rapidly urbanizing Hampton Roads area of southeastern Virginia. Sinkhole ponds are one of various types of wetlands present at the battlefield and surrounding areas. The sinkholes were formed by the collapse of surface sediments after the dissolution of shell material in underlying sediments. In a typical year, water fills the sinkholes from December to the end of July, forming shallow, seasonal ponds. These ponds primarily are present on the Grafton Plain (fig. A1). Second-growth hardwoods and pines surround many of the ponds. The combination of varied size and hydroperiods (seasonal pattern of water levels) of the ponds and varied amounts of shade from the canopy of the trees provides habitat that supports diverse communities of wetland flora and fauna. Because these ponds are seasonal and generally are not connected to streams or other permanent water bodies, few large aquatic predators are present. Therefore, the ponds are important habitat for numerous amphibians and other organisms. The woodlands surrounding the ponds also are habitat for these organisms, particularly when the ponds are dry.

The ponds at the battlefield are part of the Grafton Ponds complex, one of the most environmentally sensitive environments in Virginia. Within the complex, 11 plants and animals (commonly called natural heritage resources) have been identified as rare in Virginia (Virginia Department of Conservation and Recreation, 1998). Consequently, the Virginia Department of Conservation and Recreation has designated a part of the complex south of the battlefield as a state natural area preserve, the Grafton Ponds Natural Area Preserve (fig. A1). The preserve contains 70 ponds that are located in a water-supply protection area owned by the City of Newport News. The designation as a natural area preserve includes a perpetual "Deed of Dedication" that is recorded with the property deed and that restricts future use of the land to those uses that protect its natural heritage resources. In discussing the variability among the ponds, the Grafton Ponds Natural Area Preserve Resource Management Plan (Virginia Department of Conservation and Recreation, 1998) states, "Because of this diversity, the pond complex as a whole is more

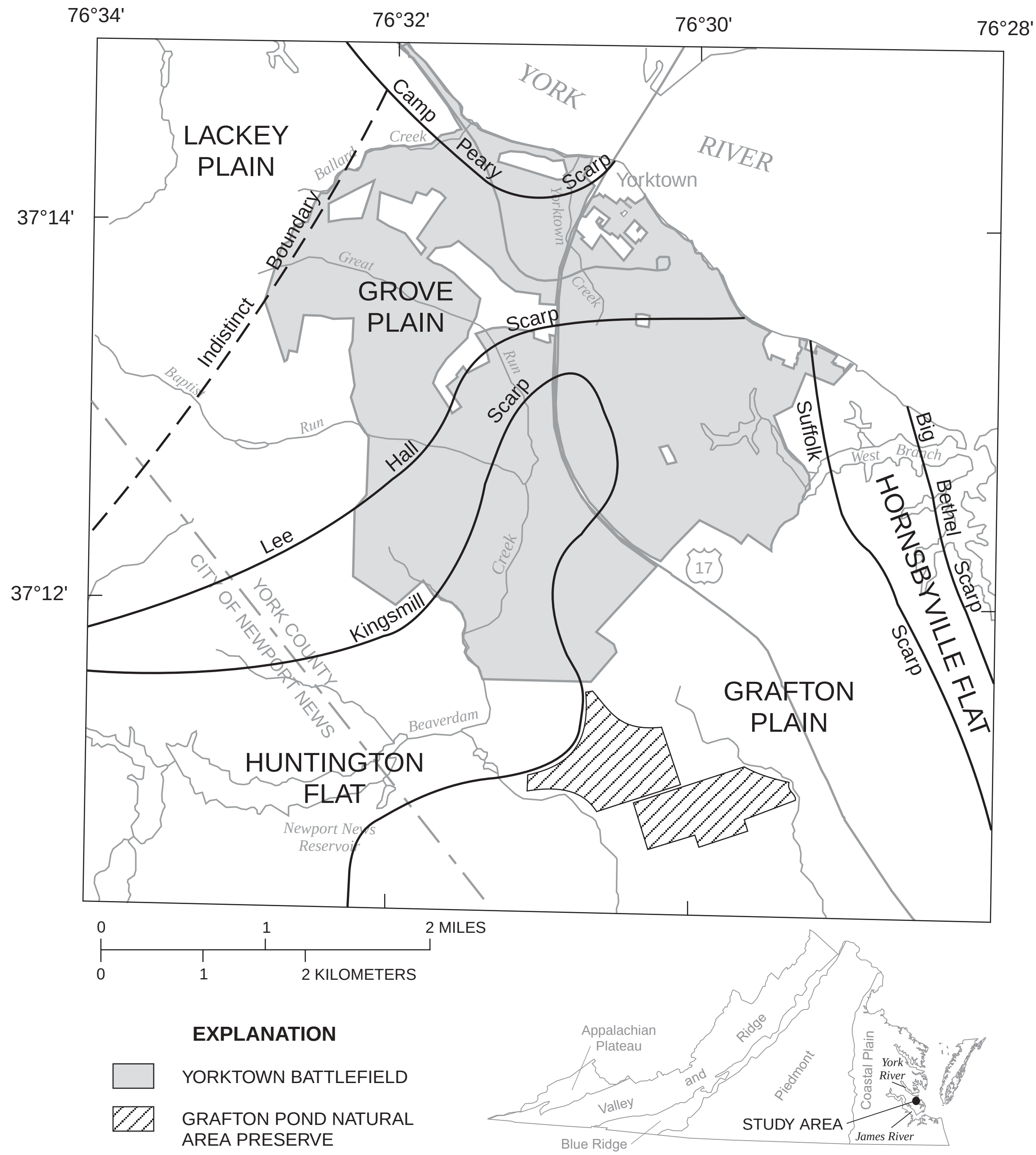

Figure A1. Location of Yorktown Battlefield, the Grafton Ponds Natural Area Preserve, and nearby physiographic features, Colonial National Historical Park at Yorktown, Virginia.

valuable ecologically than the sum of each of the ponds individually." Consequently, preserving existing ponds and restoring additional ponds, including those in Colonial National Historical Park, will help preserve these fragile environments. Preserving and restoring these ponds are important elements of the park-management plans.

Aerial photographs showed 35 possible sinkhole ponds at Yorktown Battlefield. Based on field verification of these sites and characterization of their hydroperiods and biota, only four sites meet the definition of seasonal ponds (Virginia Department of Conservation and Recreation, 1999, 2000). This definition requires that the pond is seasonally to semi-permanently flooded and supports at least one obligate wetland indicator (organism requiring a wetland to complete its life cycle) or a prevalence of facultative wetland indicators (organisms that can complete their life cycles both in and out of a wetland). Six other sinkholes located in mowed fields have been appreciably altered and have the potential to meet this definition if restored to natural conditions. Additional ponds not identified in the aerial photographs are also present at the park.

Reconnaissance water-quality sampling of selected ponds and shallow ground water by the U.S. Geological Survey (USGS) and the Virginia Department of Conservation and Recreation, Division of Natural Heritage indicates that water in the ponds is of low pH and has a low specific conductance. Thus, the ponds would have a low acid neutralizing capacity and, therefore, would be sensitive to chronic and episodic acidification from acidic atmospheric deposition. These conditions would mobilize aluminum and other heavy metals. The pH of water from two springs discharging from the Columbia aquifer at Yorktown Battlefield (the aquifer that contributes water to the ponds) was 4.5 and 5.1 units, the specific conductance was 56 and 130 μS/cm, and aluminum concentrations were 140 and 410 micrograms per liter. The pH of water from 34 ponds near the natural area preserve ranged from 4.19 to 6.40 units (median 4.55) on June 11, 1997 (Rawinski, 1997). Only three ponds had a pH greater than 5.0. In March 2000, the specific conductance of water from four ponds at Yorktown Battlefield ranged from 26 to 66 μS/cm. Details of the water quality of the ponds and possible effects of the water quality on the pond biota, however, remain uncertain.

Water quality can affect ponds as habitat for amphibians. In studies of spotted salamanders (*Ambystoma maculatum*) in ponds in eastern Virginia, Blem and Blem (1989, 1991) determined that low pH of pond water was associated with a lack of egg masses in the ponds. The lack of egg masses was also associated with aluminum, copper, and lead elevated above background concentrations; these elevated concentrations can result from the low pH. These results are similar to those of research on other amphibian habitat.

Sources of water and flow paths to and from the sinkholes affect the hydroperiods and water quality of the ponds and, therefore, affect the ponds as habitat for many organisms. Direct precipitation, surface runoff, and ground water are likely sources of water to these systems (fig. A2A); the relative contribution and effects on water quality of each source, however, are unknown. Surface runoff from the surrounding land contributes water to the ponds; the extent of the contributing area depends on the topography around each pond. Because these ponds are located on the Grafton Plain, a low-relief plain, and because woodlands surround many of the ponds, a large part of the precipitation probably infiltrates the soil and recharges the ground water.

The surficial or Columbia aquifer, the intervening Cornwallis Cave confining unit, and the underlying Cornwallis Cave aquifer are the parts of the shallow aquifer system that likely affect the hydroperiods of the ponds. The shallow aquifer system has been studied in York County (Brockman and Richardson, 1992; Richardson and Brockman, 1992) and at Yorktown Battlefield (Speiran and Hughes, 2001). Although these studies provide a general framework of the shallow aquifer system for areas near the ponds, a more detailed assessment is needed of the hydrologic connection between the ponds and the shallow aquifer system.

Because the ponds are in sediments that form the Columbia aquifer and are located in upland recharge areas, only the Columbia aquifer likely contributes ground water to most ponds. At least four types of hydraulic connection between the ponds and the shallow aquifer system are possible (fig. A2). If sediments in the bottom of the ponds are of sufficiently low permeability, the ponds can be hydraulically isolated from the Columbia aquifer, possibly creating perched conditions (fig. A2B). If the ponds are hydraulically connected to the Columbia aquifer, two conditions are possible. Where the Cornwallis Cave

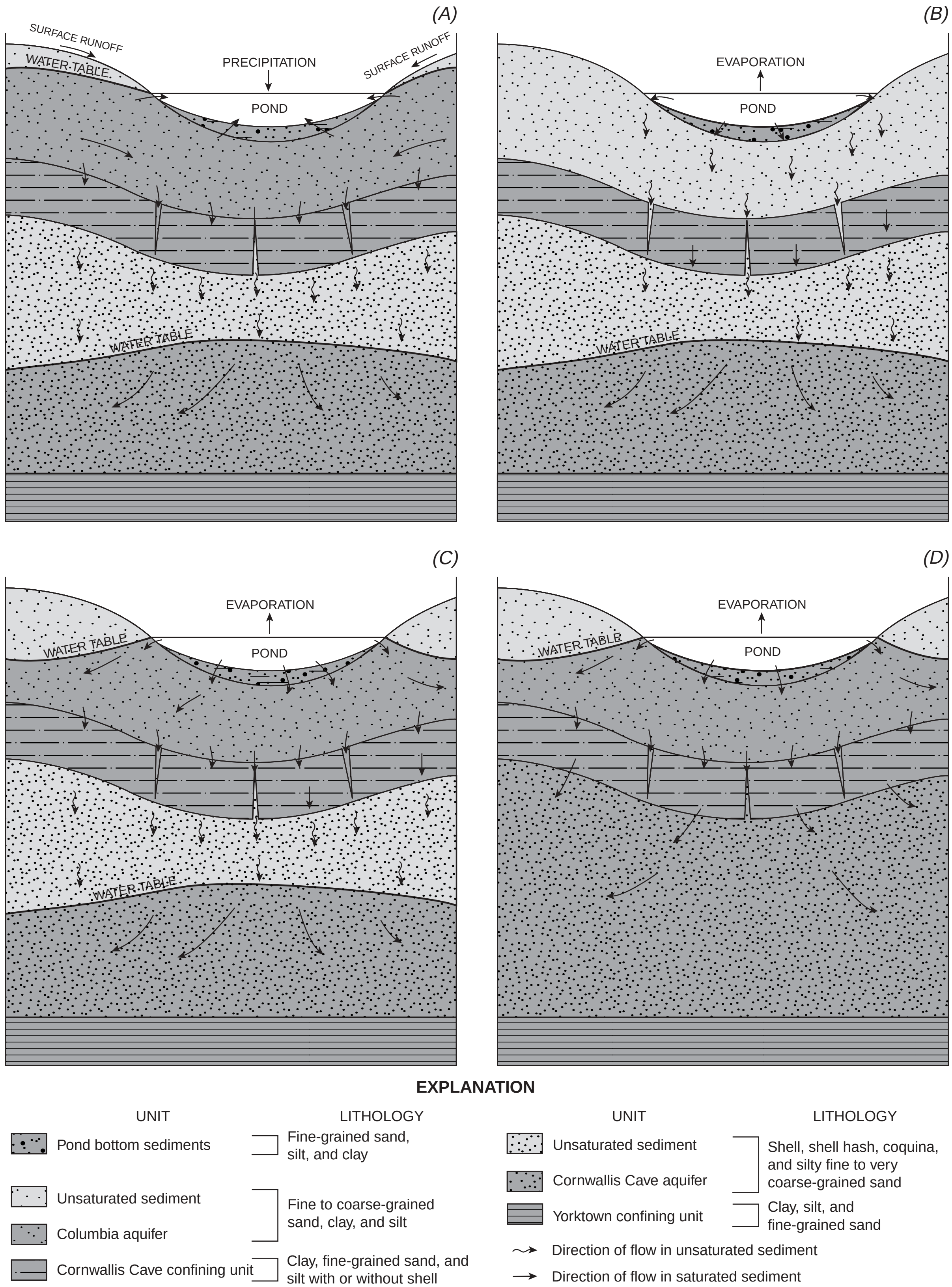

Figure A2. Selected possible hydrologic relations between the seasonal ponds and the shallow aquifer system near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia; (A) the Columbia aquifer perched and having a high water table (the upper part of the Cornwallis Cave aquifer is unsaturated), (B) the Columbia aquifer perched and having a declining water table, (C) the seasonal pond perched, and (D) the Columbia and Cornwallis Cave aquifers saturated with a declining water table.

aquifer is unconfined, the Cornwallis Cave confining unit can perch the ponds and the Columbia aquifer (fig. A2C). Where sediments in the bottom of the ponds and the Cornwallis Cave confining unit are of sufficient permeability and the Cornwallis Cave aquifer is confined, the ponds will be well connected to the Cornwallis Cave aquifer (fig. A2D).

The configuration of the Cornwallis Cave confining unit near the sinkholes can affect the hydrology of the Columbia aquifer and the contribution of ground water to the sinkholes. Because the collapse of surficial sediments results from the dissolution of shell material in the Cornwallis Cave aquifer, the Cornwallis Cave confining unit that lies between the Cornwallis Cave aquifer and land surface likely has collapsed near the sinkholes. Such collapse would alter the elevation of the top of the confining unit and the hydraulic properties of the confining unit near the sinkholes. These changes could affect the hydroperiods of the ponds by affecting the flow of ground water to the pond through the Columbia aquifer and the downward leakage of water from the pond.

Pathways for discharge of water from the ponds also affect the hydroperiods of the ponds. Evapotranspiration, surface-water drainage, lateral flow through the Columbia aquifer, and downward leakage are likely discharge pathways. Evapotranspiration is likely an important discharge pathway for most ponds. Surface-water drainage is only a discharge pathway when the level of a pond exceeds the elevation of part of the rim of the pond. Discharge to the Columbia aquifer is likely if a pond is hydraulically connected to the aquifer. Downward leakage from a pond through the underlying Cornwallis Cave confining unit and into the Cornwallis Cave aquifer is possible, depending on the hydraulic connection with the Cornwallis Cave aquifer.

The hydraulic connection between the ponds and the Cornwallis Cave aquifer is uncertain but can affect the hydroperiods in two ways. If ponds are perched, pumpage that reduces head in the aquifer will have little effect on the hydroperiods. If ponds are well connected to the aquifer and all sediments from the ponds to the bottom of the aquifer are saturated, pumpage that reduces head in the aquifer beneath the ponds would increase the downward hydraulic gradient. The increased gradient would increase the rate of downward flow of ground water, thereby reducing the hydroperiods of the ponds.

PROJECT DESCRIPTION

The purpose of this project is to evaluate the effects of hydrology on the hydroperiods and the water quality of selected sinkhole ponds. This information can be used to manage and protect those ponds and associated ecosystems that have had minimal disturbance and that meet the definition of seasonal ponds and to restore those that have been appreciably altered.

This project will be an intensive study conducted over a 3-year period. The first year will consist of characterizing the pond areas, establishing the initial data-collection network, collecting basic hydrologic and water-quality information, and finalizing the main data-collection network. Because of the amount of effort required to characterize the pond areas and establish the data-collection network, a large part of the inflow period will have passed before the data-collection network is established. The second year will be the principal year for data collection. Data collection will be at a low intensity while the ponds remain dry and will be at the greatest intensity when water inflow to the ponds is appreciable, probably from December to May; it will then decrease as inflow decreases and the ponds become dry. In the third yea, data collection will be reduced and the emphasis will be on monitoring the period of high inflow. Data will be analyzed as the project continues, and a report summarizing results will be written the third and final year of the study.

The primary data-collection sites will be four sinkhole ponds having different landscape positions and different ecological importance; two of the ponds will be minimally disturbed and two will be appreciably altered. One of the minimally disturbed ponds will be studied more intensively than the others. The data-collection network will consist of a precipitation-monitoring network, runoff-collection systems, and monitoring wells and piezometers.

Before the wells and piezometers are installed, hydrologic and geophysical surveys will be conducted. While the sinkholes contain water, mini-piezometers will be used to identify spatial differences in vertical gradients between pond levels and shallow ground-water levels. This information will be used to identify possible areas of flow into and out of the ponds. Surface-geophysical surveys also will be conducted to evaluate subsurface geohydrologic features near the sinkholes. The most appropriate techniques will be determined in consultation with the Branch of

Geophysical Applications and Support of the USGS; DC resistivity appears to be one technique that will be useful. Results of both surveys will be used to select sites for well installation. After wells have been installed, borehole geophysical logs will be run on wells of sufficient depth. The surface-geophysical survey will then be interpreted in greater detail by use of the lithologic logs and borehole geophysical logs.

Wells will be installed in the Columbia aquifer to evaluate hydraulic gradients, the flow of water between the ponds and the aquifer, and the possible effects of such flow on the hydroperiods and water quality of the ponds. Two transects of well clusters will be constructed orthogonal to each other across, and outside of, the selected sinkholes. Holes will be hand augered to the Cornwallis Cave confining unit, if possible, at each well site. Information from the auger holes along with results of the surface-geophysical survey will be used to determine the configuration of the top of the confining unit. At each site possible, one well will have a 1-ft-long screen open just above the confining unit; one will have a 1- to 5-ft-long screen open from near land surface to below the water table. If the well site is inside the maximum perimeter of a pond, the top of the screen of the shallow well will be at least 1 ft below the bottom of the pond so that water levels and quality in the well will not be directly affected by water in the pond. The annulus between the well and the wall of the borehole will be sealed with bentonite above the top of the screen to prevent an increased hydraulic connection between the pond and the aquifer.

Additional wells will be installed in the Cornwallis Cave aquifer at selected clusters to determine if the sinkholes are perched or if all sediments below the sinkholes are saturated. These wells will be installed at two clusters at two sinkholes: one cluster inside of each sinkhole, and one cluster outside of each sinkhole. Wells will be installed with screens open to the top and bottom of the Cornwallis Cave aquifer, if possible.

Vertical hydraulic conductivity and specific yield will be analyzed for selected sediment cores. Vertical hydraulic conductivity will be used to evaluate the vertical hydraulic connection between the ponds and the Cornwallis Cave aquifer. Specific yield of shallow sediments will be analyzed to help evaluate the amount of ground-water recharge and discharge.

Water levels will be measured periodically in all wells and associated ponds to determine seasonal changes in the levels, vertical and lateral hydraulic gradients, and the vertical continuity in saturation of the sediments. Water levels will be measured continuously in selected wells and two ponds to evaluate lateral and vertical changes in hydraulic gradients between the ponds and the aquifer that result from the combination of surface runoff and ground-water recharge. Continuous ground-water levels will be used to evaluate the effects of ground-water recharge and evapotranspiration.

Pond water, surface runoff, and ground water will be sampled and analyzed for a variety of properties. Specific conductance, pH, and temperature of water from selected wells and the ponds will be periodically determined in the field. Samples from a smaller number of selected wells and the ponds will be analyzed for concentrations of major ions; nutrients; organic carbon; trace metals; the stable isotopes of oxygen, hydrogen, and nitrogen; dissolved gases; and tracers used for age-dating ground water. Not all properties will be determined for all samples. Results of these analyses will be used to assess water sources and flow paths, the water quality of the ponds, and the effects of water sources and flow paths on the water quality.

Water-level and water-quality data collected during this study at other ponds in the Grafton Ponds Complex will be supplied by the Division of Natural Heritage. These data will be compared with data collected as a part of this study to determine the comparability of the ponds at the battlefield with those in the preserve. The Division of Natural Heritage will also provide field support for installation of the data-collection network and for data collection. Staff of the National Park Service (NPS) will provide global positioning system (GPS) support and digital photographs of the ponds and data-collection network. NPS staff and (or) student volunteers will also help in the collection of data immediately following storm events. Gerald Johnson, Professor at the College of William and Mary, and C. Richard Berquist, geologist at the Virginia Division of Mineral Resources, will provide technical assistance in the evaluation of the geology of the sites.

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RANKING CRITERIA

1. Significance of the Resource or Issue to the Park

Although sinkhole ponds cover a small part of the park, the ponds provide important habitat for numerous organisms. Preservation of the ponds at Yorktown Battlefield would help extend the area of the pond complex preserved in the Grafton Ponds Natural Area Preserve south of the park, thereby reducing the possible isolation of this ecosystem. Because of the limited disturbance of the land at the Yorktown Battlefield, the park provides an opportunity to protect a type of ecosystem that is subject to the effects of development in many areas outside of the park. Selected sinkholes in mowed areas potentially can be restored to natural conditions, thereby further increasing the extent and number of protected ponds. Preserving and restoring these ponds is an important element of the park-management plans.

2. Severity of Resource Threat, Problem, or Need

Yorktown Battlefield is located in the rapidly urbanizing Hampton Roads area of southeastern Virginia. Increased urbanization has destroyed or appreciably altered many of the ponds and associated ecosystem in the Grafton Ponds Complex. Continued urbanization will further threaten these ponds and ecosystems.

3. Problem Definition and Information Base

The plant and animal communities of the Grafton Ponds Complex have been extensively inventoried and evaluated (Rawinski, 1997; Roble, 1998). Recent studies at Yorktown Battlefield have inventoried sinkhole ponds that were identified from aerial photographs and have inventoried the biota of these ponds. Ponds not identified in the photographs, however, are present at the park but have not been inventoried. Basic evaluations of the framework, hydrology, and water quality of the shallow aquifer system with which the ponds interact have been conducted (Brockman and Richardson, 1992; Richardson and Brockman, 1992; Speiran and Hughes, 2001). The effects of the hydroperiods and water quality on the suitability of the ponds as habitat for the biota, however, have not been assessed.

4. Feasibility

The objectives of the project can be accomplished with the full funding and in the timeframe (3 years) of the study.

5. Problem Resolution

Understanding the hydrology of the sinkhole ponds will provide information essential for the NPS to manage and protect the ponds and associated ecosystems. This information can also be used in possible restoration of the habitat in sinkholes in areas that have been appreciably altered by mowing or other activities.

6. Transferability

Knowledge provided by this project will be directly applicable to other ponds in the Grafton Pond Complex. Such information will be critical in managing and protecting the ponds inside and outside of the park as a unified ecosystem. Results of the study also could be useful in understanding the hydrology and water quality for managing and protecting seasonal ponds in similar geohydrologic environments.

7. Cost Effectiveness

This study will provide the knowledge necessary to effectively manage sinkhole ponds and provide the desired level of protection. This information will help to differentiate those activities that pose a serious threat to the ecology of the ponds from those that pose minimal threat. In addition to providing information on the sinkholes, this project will provide key information on the framework and hydrology of the shallow aquifer system at the park. This information will provide a baseline for long-term hydrologic and water-quality monitoring that will be important for other projects concerning ground-water, surface-water, and water-quality issues at Yorktown Battlefield.

PROJECT STATEMENT 2

Title: Effects of Ground-Water Discharge from the Shallow Aquifer System on the Water Quantity and Quality of Nontidal Streams and Riparian Wetlands, Yorktown Battlefield, Virginia

Park: Colonial National Historical Park- Yorktown Battlefield

Service-Wide Issues:

Amount Requested: $550,000 over three years

Park Contact: Charles Rafkind

ABSTRACT

Ground-water discharge likely contributes about 50 to 75 percent of the water to streams and associated riparian wetlands at Yorktown Battlefield, Colonial National Historical Park, Virginia. These streams and wetlands provide (1) critical habitat for rare, threatened, and endangered species, (2) nurseries for numerous commercial and recreational sport fishery species, and (3) opportunities for observation, education, and recreational fishing. Although these ecosystems are not unique within the region, their presence in the park provides an opportunity to manage and protect these ecosystems in a manner that is limited outside of the park. Knowledge of the effects of ground-water discharge on the quantity and quality of water in these environments, therefore, is critical to the management and protection of these streams, wetlands, and associated aquatic ecosystems. The purpose of this project is to evaluate the effects of ground-water discharge on the quantity and quality of water in the streams and associated nontidal riparian wetlands at Yorktown Battlefield.

PROBLEM

Yorktown Battlefield, Colonial National Historical Park, is located in the Coastal Plain of Virginia between the James River and York River estuaries (fig. A1). Beaverdam Creek and its tributaries drain to the James River estuary. Three small streams and their tributaries drain to the York River estuary. Wetlands at the park include palustrian-forested wetlands in the valleys of most streams, tidal marshes in the lower parts of tributaries to the York River, and seasonal sinkhole ponds in the uplands. These streams and wetlands provide (1) critical habitat for rare, threatened, and endangered species, (2) nurseries for numerous commercial and recreational sport fishery species, and (3) opportunities for observation, education, and recreational fishing. Although these ecosystems are not unique within the region, the park provides an opportunity to manage and protect these ecosystems in a manner that is limited outside of the park.

Because the streams and wetlands are well connected to the shallow aquifer system, ground water discharge can appreciably affect the quantity and quality of water in these environments. Although the contribution of ground water to streamflow has not been evaluated at Yorktown Battlefield, ground-water discharge contributes 47 to 79 percent of the annual streamflow across the Coastal Plain of Virginia (Richardson, 1994).

Upper parts of the basins draining to many of the streams and associated riparian wetlands at Yorktown Battlefield originate outside the park. Consequently, land use and hydrologic and geochemical processes outside of the park affect the quantity and quality of water in the streams and riparian wetlands of the park. Because of the connection between the park and surrounding areas, park managers work closely with planners and managers of other agencies to help manage the region’s resources in a manner compatible with park objectives. Knowledge of processes that control the quantity and quality of water in the streams and riparian wetlands of the park is necessary to communicate the implications of local land-use management on the aquatic resources of the park. Because the characteristics of the parts of these systems inside and outside of the park are similar, managers outside of the park can use knowledge obtained inside of the park.

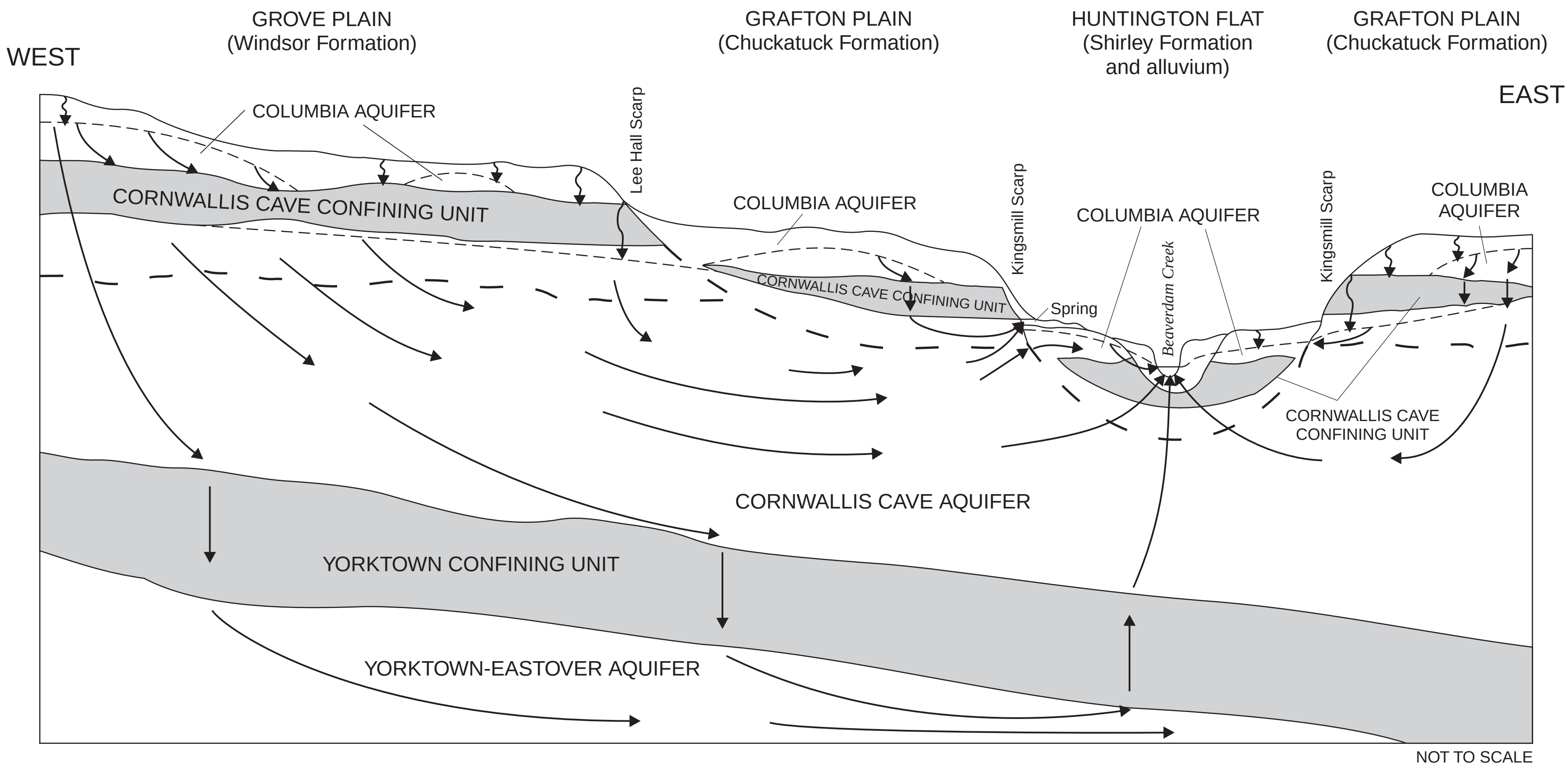
Although the shallow aquifer system at Yorktown Battlefield is part of a system that extends into surrounding areas, stream incisement into the shallow aquifer system probably limits the lateral and vertical extent of shallow ground-water flow. The shallow aquifer system near Yorktown Battlefield (from shallowest to deepest) consists of the Columbia aquifer, the Cornwallis Cave confining unit, the Cornwallis Cave aquifer, the Yorktown confining unit, and the Yorktown-Eastover aquifer (Brockman and Richardson, 1992; Brockman and others, 1997) (fig. A3). Most of the ground water flows through the Columbia and Cornwallis Cave aquifers because of stream incisement into these aquifers. Because of the spatial variability in the near-surface geology at the park (Johnson, 1972) and because of stream incisement into shallow sediments, the extent and characteristics of the Columbia aquifer and Cornwallis Cave confining unit vary spatially across the park. Such variability affects the hydrologic connection between the shallow aquifer system and the streams and riparian wetlands.

The discharge of ground water varies spatially across the park. Ground water typically recharges in the uplands and discharges to ditches, seeps, springs, streams, and wetlands (fig. A3). A substantial amount of ground water discharges through springs that generally are located at the base of valley slopes, in stream valleys, and in streambeds. Ground water also discharges diffusely through streambeds and across riparian wetlands as evapotranspiration. Because streams in the York River Basin incise more deeply into aquifer sediments and have steeper valley walls than streams in the James River Basin, the characteristics of the hydraulic connection and ground-water discharge likely differ between the basins.

The contribution of ground-water discharge to streamflow and evapotranspiration relative to other sources of water also varies temporally. During stormflow periods, streamflow consists of a combination of direct precipitation, surface runoff, and ground-water discharge; during base-flow periods, natural streamflow is entirely ground-water discharge. When streamflow is high, riparian wetlands can become inundated by stream water; the effects of ground water on these wetlands are limited. When standing water is absent across much of the wetlands and precipitation is limited, ground water can be the only source of water available for evapotranspiration. Thus, ground water can be an essential source of water for sustaining the vegetation in many wetlands during dry periods. Additionally, because ground water is an important source of water to the streams and riparian wetlands at the park, ground water can appreciably affect the water quality of these streams and wetlands and can be an important source of nutrients and possibly other contaminants.

The quality of ground-water discharge is controlled by a combination of land use, natural sources, and natural hydrologic and geochemical processes. Land use in the park primarily consists of forests and fields. Urban areas that are not part of park property are located inside the outer boundary of the park. A combination of forested and developed land covers outside areas draining to the park. The mineral and organic content of the aquifers are natural sources for dissolved constituents in ground-water discharge. Aquifer and confining unit composition and topography are the primary factors that affect hydrology. The mineral and organic content and hydrology of the aquifers and confining units control aquifer geochemistry. Thus, characteristics of the aquifers through which ground water flows and discharges can appreciably affect the quality of ground-water discharge.

The effects of the Columbia aquifer on ground-water quality appear to differ from those of the Cornwallis Cave aquifer. Water that only flows through the Columbia aquifer before discharging, for example, is acidic (pH less than 5.0) and has a low acid neutralizing capacity. Because of the high shell content of the Cornwallis Cave aquifer, however, water that flows through this aquifer along part of its flow path generally has a neutral to basic pH and a high acid neutralizing capacity. Such differences in water quality can affect constituents that are transported from land surface or derived from the aquifers. Water from the Columbia aquifer that has a low pH can potentially have high concentrations of heavy metals derived from aquifer sediment or other sources, whereas concentrations likely are low in water that flows through the Cornwallis Cave aquifer.



EXPLANATION

CONTACT BETWEEN THE MOORE HOUSE MEMBER OF THE YORKTOWN FORMATION AND THE OVERLYING TERRACE DEPOSIT

GROUND-WATER FLOW PATH

PERCOLATING RECHARGE

WATER TABLE

Figure A3. Generalized relation between geology and geohydrologic units and ground-water flow paths near Yorktown Battlefield, Colonial National Historical Park at Yorktown, Virginia.

Another likely effect on ground-water quality is the presence of abundant organic material in parts of the Columbia aquifer. Dissolved oxygen will likely become depleted in water that flows through such parts of the aquifer. Low dissolved-oxygen concentrations will alter the chemistry of the ground water, resulting in denitrification of nitrate and other possible geochemical processes.

Consequently, knowledge of the effects of ground-water discharge on the quantity and quality of water in streams and riparian wetlands is essential to effective management and protection of the natural resources at Yorktown Battlefield. Such knowledge is needed to differentiate the effects of ground-water discharge from those of surface runoff on stream-water quality. This knowledge is also needed to develop management practices inside and outside of the park that will protect stream-water quality in the park. This knowledge can also be used to help develop an effective surface-water-quality monitoring program.

PROJECT DESCRIPTION

The purpose of this project is to determine the effects of ground-water discharge on the quantity and quality of water in streams and nontidal riparian wetlands at Yorktown Battlefield. In particular, the timing, location, and potential magnitude of these effects will be evaluated. Park staff will use this information (1) to protect and manage the aquatic ecosystems, (2) to work closely with planners and managers of other agencies to help manage the region’s resources outside of the park in a manner compatible with park objectives, and (3) to design an effective surface-water-quality monitoring program.

Because the hydraulic connection and the nature of ground-water discharge to streams in the James River Basin apparently differ from those in the York River Basin, the study will include sites on Beaverdam Creek and its tributaries (James River Basin) and on Yorktown Creek and its tributaries (York River Basin) (fig. A1). Each basin will be studied as a separate hydrologic system, and the characteristics of the two systems will be compared.

A combination of ground-water and surface-water information will be collected as a part of short-term (several weeks) synoptic studies and continuous, long-term (1 to 2 years) monitoring. Ground water will be monitored at springs, individual wells, clusters of wells, mini-piezometers temporarily installed in streambeds, and seepage collectors temporarily installed in streambeds. Spring discharge, streamflow, ground-water levels, and ground-water and stream-water quality will be measured during one high and one low base-flow synoptic study. Ground-water levels and general ground-water and stream-water quality will be monitored periodically at selected sites. Streamflow and ground-water levels will be monitored continuously at selected sites. Because flow in Yorktown Creek is largely tidal, streamflow will not be continuously monitored on Yorktown Creek.

Before installing fixed-location data-collection sites, hydrologic and geophysical surveys will be conducted to identify spatial differences in the aquifer and confining unit sediments and areas of ground-water discharge and recharge through streambeds. Surface-geophysical surveys will be conducted from the uplands on one side of the streams across the riparian wetlands to the uplands on the other side of the streams. The most appropriate techniques will be determined in consultation with the Branch of Geophysical Applications and Support of the U.S. Geological Survey; DC resistivity appears to be one technique that will be useful. These surveys will be used to evaluate the continuity and discontinuity in sediments of the Columbia aquifer and the Cornwallis Cave confining unit. Surveys also will be used to evaluate the depth of the water table and possibly the depth of the Yorktown confining unit.

Other types of surveys will be conducted to evaluate ground-water discharge and recharge through streambeds. Streamflow will be measured at intervals along the streams to identify reaches of water gain (ground-water discharge) and water loss (ground-water recharge). Temporary mini-piezometers will be driven into streambeds at points in sections across the streams to identify differences in vertical gradients between ground-water levels and stream-water levels. Seepage collectors will be installed temporarily and monitored in selected areas having upward gradients to identify local differences in the rate and general water quality of ground-water discharge. Collectively, this information will be used to select sites for well and streamflow-gage installation and sites for data collection during synoptic studies.

Clusters of wells will be installed in transects from the uplands on one side of the stream across the riparian wetlands to the uplands on the other side of the stream. Holes will be hand augered through the

Cornwallis Cave confining unit into the Cornwallis Cave aquifer, if possible, at each well site. Clusters will contain wells having screens open to the top and bottom of the Columbia aquifer where sediments of the Columbia aquifer are saturated; wells will be open to the top and bottom of the Cornwallis Cave aquifer where possible. Additional wells will be installed in the Cornwallis Cave aquifer (where such wells cannot be installed in hand-augered holes) and in the top of the Yorktown-Eastover aquifer by use of an auger rig or geoprobe at selected sites. These wells will be installed at one site in the uplands on either side of the stream and at one site adjacent to the stream in at least one transect. Information from the auger holes and results of the surface-geophysical surveys will be used to refine the framework of the shallow aquifer system along the transects. Frameworks along the transects will be incorporated into the existing general framework for the entire park.

Vertical hydraulic conductivity and specific yield will be analyzed for selected sediment cores. Vertical hydraulic conductivity will be used to evaluate the vertical hydraulic connection between aquifers and between the Columbia aquifer and the streams. Specific yield of shallow sediments will be analyzed to help evaluate the amount of water discharged by evapotranspiration and other pathways.

Precipitation amounts will be monitored continuously at a field in the Beaverdam Creek Watershed. Precipitation amounts and timing will be compared to streamflow and ground-water levels.

Water levels will be measured periodically in wells and adjacent streams and wetlands to determine seasonal changes in ground-water levels, vertical and lateral hydraulic gradients, and the vertical continuity in saturation of the sediments. Water levels will be measured continuously in selected wells to evaluate short-term changes in ground-water levels that include the effects of recharge and discharge to evapotranspiration and streams.

Streamflow and stream-water temperature and specific conductance will be monitored continuously at two sites in the Beaverdam Watershed. This information will be used to separate base-flow from stormwater-runoff periods.

Ground water from wells, spring water, stream water, and ground-water seepage from the streambed will be collected and analyzed for a variety of properties. Specific conductance, pH, water temperature, and concentrations of dissolved oxygen will be determined periodically in the field in water from selected wells, springs, and sections in the streams. Samples also will be collected during a spring base-flow period from a smaller number of selected wells, springs, mini-piezometers, seepage collectors, and stream cross sections for analysis of concentrations of major ions; nutrients; organic carbon; heavy metals; the stable isotopes of oxygen, hydrogen, and nitrogen; dissolved gases; and tracers used for age-dating ground water. Not all properties will be determined for all samples. Results of these analyses will be used to assess the effects of ground-water discharge on the quality of water in streams and riparian wetlands at Yorktown Battlefield.

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RANKING CRITERIA

1. Significance of the Resource or Issue to the Park

The streams and riparian wetlands of Yorktown Battlefield provide important habitat for numerous species. Although no ecosystem is unique in the region, riparian wetlands in lower Beaverdam Creek and an unnamed tributary in the lower part of the basin are part of critical habitat for rare, threatened, and endangered species. Other areas are nurseries for important commercial and recreational sport fishery species. Additionally, many areas also provide unique opportunities for observation, education, and recreational fishing that are important in the rapidly urbanizing Hampton Roads area. Because of the limited disturbance of the land at Yorktown Battlefield, the park provides an opportunity to protect types of aquatic ecosystems that are subject to the effects of development in rapidly urbanizing areas outside of the park. Protection of these areas at the park can serve as a model for the surrounding area.

2. Severity of Resource Threat, Problem, or Need

Yorktown Battlefield is located in the rapidly urbanizing Hampton Roads area of southeastern Virginia. Most of the streams and riparian wetlands at Yorktown Battlefield are parts of systems that extend beyond the park. As such, activities outside of the park can affect the quantity and quality of water in streams and wetlands at the park. Because land use at the park can be controlled, aquatic ecosystems inside the park can be better preserved and managed than many of those outside the park. Some of the possible threats, problems, and needs, however, remain uncertain because studies of off-site effects on the water quality of streams and wetlands at Yorktown Battlefield have been limited.

3. Problem Definition and Information Base

Ground-water discharge can appreciably affect the quantity and quality of water in streams and riparian wetlands at Yorktown Battlefield. Possible effects of the ground-water discharge, however, have not been studied. Studies of the water quality of the nontidal streams and riparian wetlands are also limited such that potential problems have not been identified.

4. Feasibility

The objectives of the project can be accomplished with full funding and in the timeframe (3 years) of the project.

5. Problem Resolution

Effective management and preservation of the aquatic resources and monitoring of the water quality at Yorktown Battlefield depend on knowledge of the effects of ground-water discharge on the quantity and quality of water in streams and riparian wetlands. Although additional information will be needed, this study will provide information essential to achieving these goals. Results of this study can be used to help establish effective long-term monitoring of ground-water and surface-water quality and will provide a basis for evaluation of the monitoring data. This research will provide necessary base-line information for managing and preserving the streams, wetlands, and associated aquatic ecosystems at the park.

6. Transferability

Because the hydrologic system at Yorktown Battlefield extends beyond the park, this information can be directly transferable to other areas in the region. This is particularly important to park managers because many of the streams that drain the park flow into the park from surrounding areas. Thus, other agencies can use this information for managing and protecting streams and wetlands outside of the park, including those that affect the park.

7. Cost Effectiveness

This project will provide essential information for (1) the protection and management of streams, riparian wetlands, and associated critical aquatic ecosystems at the park, (2) the design of effective surface-water and ground-water quality monitoring programs, and (3) the analysis of results from these programs. Without knowledge provided by this study, management of these areas will be less effective and could fail to provide the desired level of protection. This information can be used to plan the frequency and timing of sample collection that can be designed to target desired conditions. In so doing, a cost-effective long-term monitoring program can be developed. In addition to providing information on these systems, this project will provide key information on the framework and hydrology of the shallow aquifer system at the park. This information will be important for other projects concerning ground-water and surface-water issues at Yorktown Battlefield.